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## Abstract

This study investigated the design, enactment, and impact of an undergraduate, inquiry-based astronomy laboratory learning environment. The professor, Richard, adopted laboratory materials from the Center for Astronomy and Physics Education Research [CAPER] which were described by the group as inquiry-based. Students worked through these laboratory materials under the supervision of teaching assistants [TAs], and Richard led weekly TA meetings to monitor and instruct the TAs on his expectations. This study suggests that Richard was unsure of laboratory materials' learning goals and had received limited guidance on how to use and implement CAPER's materials. TAs also received limited guidance on how to interact with their students while they worked through the laboratory materials. TAs gave introductions during laboratory sessions that were similar to Richard's introductions given during weekly TA meetings. Data from this study suggests that most students were able to easily complete the laboratory materials without the assistance of their TA. When students did ask questions, questions were focused on obtaining the correct answer which TAs normally supplied through direct responses or questioning. This laboratory learning environment was found to have no impact on students' understanding of the nature of scientific inquiry, as measured by VOSI, which contradicts previous research findings associated with the materials. I suggest that professors should be cautious when adopting curriculum materials. Curriculum designers should provide information related to the design of their materials, the learning goals of those materials, sample student responses, and effective implementation strategies.

THE DESIGN, ENACTMENT, AND IMPACT OF AN UNDERGRADUATE, INQUIRY-  
BASED, ASTRONOMY LABORATORY LEARNING ENVIRONMENT.

by

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B.S. Physics, SUNY at Oneonta, 2004

Dissertation

Submitted in partial fulfillment of the requirements for the degree of  
Doctor of Philosophy in College Science Teaching.

Syracuse University  
June 2013

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## **Chapter 1: Introduction**

In a nation that is heavily influenced by science and technology, it is imperative that our schools provide successful science learning experiences and develop science literacy for all students K-16. Many national efforts have been made to enhance the quality of teaching and learning in K-12 science education (National Research Council [NRC], 1996, 2012; American Association for the Advancement of Science [AAAS], 1989, 1993) and these efforts use ‘inquiry’ as their organizing theme (Anderson, 2007). Inquiry, in the most basic sense, entails providing students with opportunities with appropriate teacher-guidance to ask questions, to collaboratively design studies to investigate those questions, and to generate evidence-based claims. Empirical studies in K-12 education have shown moderate success of inquiry-based learning environments in terms of the uptake of K-12 inquiry teaching as well as increasing students’ conceptual understanding of science concepts (Minner, Levy, & Century, 2010). Although K-12 education certainly warrants the attention it receives, undergraduate science education is equally important.

Undergraduate science courses often represent the final formal exposure to science for many students (Deming & Hufnagel, 2001). Unfortunately, despite constant calls for undergraduate science education reform (NRC, 1997, 1999, 2012), lecture-based classes are arguably the most common form of undergraduate science education experiences while student-centered learning environments remain rare. Science educators have attempted to fix this situation in various ways. Some researchers, for example, have assumed that K-12 teachers’ classroom practices can be improved by modifying their beliefs about effective teaching and learning (Jones & Carter, 2007). Researchers have also begun to investigate the teaching and learning beliefs of professors in undergraduate science education.

Studies suggest that while science professors possess adequate views of the process of scientific inquiry (Harwood, Reiff, & Phillipson, 2002) they have limited views of the teaching of inquiry (Brown, Abell, Demir, & Schmidt, 2006) which is a major barrier to inquiry-based instruction entering the undergraduate science experience (Cheung, 2007). Some have argued the undergraduate science laboratory learning environment should implement inquiry-based teaching practices (Hofstein & Lunetta, 1982, 2004). Unfortunately, many undergraduate science laboratories only involve students following cookbook-like procedures to verify known results (Hofstein & Lunetta, 2004). Further, many undergraduate science laboratories are taught by teaching assistants [TAs] who typically have limited teaching experiences and training in educational pedagogy and/or may possess varying interest and knowledge related to the subject matter (Park, 2004). Highly structured labs supervised by TAs with little teaching experience may not be an environment conducive to the learning goals recommended by science educators.

Encouragingly, some professors participate in professional development programs with the hope of changing their teaching practices. Research suggests that when professors develop an understanding and appreciation of student-centered learning environments and become reflective in their teaching practices, they may become successful inquiry teachers (Ash, Brown, Kluger-Bell, & Hunter, 2009). However, most professors do not attend professional development programs and so the task of science educators has been to develop other ways to transform undergraduate science instruction. A common method science educators use to influence classroom instruction is through the dissemination of curriculum materials. For example, in physics and astronomy, many curriculum materials are available for teacher consumption (e.g., McDermott & Shaffer, 2002; Slater, Slater, & Lyons, 2010; Prather et al., 2005). However, adoption of curriculum materials does not guarantee instructional change (Brown, 2009). Teachers adopt and then interpret, translate, modify, and

implement curriculum materials in unique ways (Brown 2009; Remillard, 2007). Considering the number of curriculum materials available for direct adoption, especially in physics and astronomy, understanding how professors interpret, modify, and adapt such materials is important.

A large-enrollment introductory astronomy course at a research university provided the context for this study. The course lectures were taught by a professor, given the pseudonym Richard, who at the time of this study had four years of college teaching experience. This particular astronomy course had an accompanying laboratory section that was supervised by TAs who were doctoral students in the physics department. Richard previously participated in two professional development programs that encouraged adoption of student-centered learning activities designed to improve students' understanding of astronomy content during lectures. While Richard experienced success with many of these student-centered learning activities in his lectures, the laboratory experience remained highly structured and he described how students' attitudes towards the astronomy laboratory learning environment were overwhelmingly negative and the laboratory experiences were judged by students to be tedious and unrelated to lecture materials.

In the fall semester of 2011, Richard adopted new curriculum materials for use in the laboratory. The curriculum materials were called *Engaging in Astronomical Inquiry* (Slater et al., 2010). These materials served as a replacement for the traditional "cookbook" laboratory activities used during previous semesters. The curriculum developers described their materials as inquiry-based and argued that their materials facilitated students' understanding of the nature of scientific inquiry [NOSI]. Richard held weekly TA meetings where he communicated TAs' roles and expectations. The astronomy laboratory learning environment, as well as the weekly TA meetings, provided the specific context for this study. The specific purposes of this study were two-fold. First, I investigated how a beginning professor and TAs designed and enacted an undergraduate inquiry-based astronomy

laboratory learning environment. Second, I investigated the impact of this undergraduate inquiry-based learning environment on students' understanding of NOSI.

### **Theoretical Frameworks.**

Two theoretical frameworks influenced this study: constructivism and the teacher-curriculum materials relationship.

#### **Constructivism.**

Constructivism has been perhaps the most influential theoretical idea within science education of the past half century. Broadly speaking, constructivism is an umbrella term that has been used by many scholars from many disciplines for different reasons (Matthews, 1998, 2002; Osborne, 1996; Guo, 2007). Constructivism has been construed to mean (a) a theory of learning, (b) a theory of teaching, (c) a theory of personal construction of knowledge, or (d) a theory of scientific construction of knowledge (Matthews, 2002). For my research, constructivism is to be understood in context of the social learning of individuals, and this is heavily influenced by contemporary theories of how people learn (Ormrod, 2003; Bransford, Brown & Cocking, 1999).

Prior to the 1950s, most American researchers studied human learning from a behaviorist perspective (Ormrod, 2003). Eventually, behaviorist models of human learning became replaced with cognitive and social models of learning (Ormrod, 2003). These models generally entail the following characteristics about human learning (Anderson, 2007):

- (a) Learning is an active process of individuals constructing meaning for themselves; significant understandings are not simply received.
- (b) The meanings individuals construct are dependent upon the prior conceptions this individual already has. In the process, these prior conceptions may be modified.

(c) The understandings individuals develop are dependent upon the contexts in which the meanings are engaged. The more abundant and varied these contexts are, the richer are the understandings acquired.

(d) Meanings are socially constructed; understanding is enriched by engagement of ideas in concert with other people. (p. 809)

These four characteristics represent the foundation of much research in science education and I adopted this framework as a way to examine and make sense of the laboratory learning environment in this study. More specifically, I used this framework as a lens through which I constructed my understandings of how Richard and the TAs designed and enacted this laboratory curriculum.

### **The teacher-curriculum materials framework.**

In this section, I outline the nature of the relationship between teachers and the curriculum materials they may adopt for classroom use. I draw from the work of Brown (2009), Remillard (2007), Davis and Krajcik (2005), and Schneider and Krajcik (2002). By surveying this work, I argue that teaching is fundamentally and appropriately conceived of as a design activity. That is, a learning environment is intentionally designed by a teacher and often this design involves adoption, interpretation, and adaption of curriculum materials. Although curriculum materials are traditionally thought of as educative for students, I argue that curriculum materials can also be educative for teachers (Schneider & Krajcik, 2002).

To understand the complex relationship between curriculum materials and the practices they facilitate, Brown (2009) offered the following analogy:

The song *Take the A Train*, written by Billy Strayhorn, was the signature tune of the Duke Ellington Orchestra, and was performed by countless others. If we compare Duke's rendition to one by Ella Fitzgerald, we have little difficulty identifying each rendition as being the same

song. Yet, despite their essential similarities, the songs sound distinctly different... although performers use pre-rendered scores as foundations to support their practice, a great deal of the creative work takes place during practice. (p. 17)

Brown argued that a similar relationship exists between teachers and the curriculum materials they adopt. For instance, two teachers who adopt, say, astronomy laboratory materials, will end up constructing different learning environments because each interprets, adapts, and modifies the various words and representations in the materials. Just as no two renditions of a particular musical number will be exactly alike, no two enactments of a set of curriculum materials will be exactly alike. The curriculum materials, being nothing more than words on paper, are static, inert representations of abstract concepts that come to life only through interpretation and use by teachers and their students.

Brown (2009) synthesized research on how teachers interpret and use curriculum materials and described several common themes. He found that teachers adopt curriculum materials, interpret those materials while designing the learning environment, reconcile differences between the designer's intended goals and their own personal goals, and also add, modify, and/or omit certain features of the materials that do not interest them or are perceived to be irrelevant to their specific learning environment. If we accept the view that teaching is a design activity involving adoption, interpretation, and modification, then it would seem worthwhile to examine how K-16 teachers engage in this process. This is especially the case considering the numerous curriculum materials made available for professors (Henderson et al., 2012). This provided the initial desire to study the design of the astronomy laboratory learning environment which served as part of the context of this study. Brown (2009) however, does not indicate ways in which researchers can conceptualize the relationship between the curriculum materials and the teachers who adopt, interpret, and adapt them.



For this, I turned to Remillard's (2007) review of curriculum material use research in mathematics education.

Remillard (2007) reviewed 25 years of research related to curriculum material use in mathematics education. Although her review was in mathematics education, this is also relevant for science education because in either case, teachers adopt, interpret, and adapt curriculum materials. In her review of the literature, Remillard examined the ways in which *curriculum material use* had been conceptualized by researchers over the 25 years. She argued that researchers have conceptualized curriculum material use in four ways. The first framework was *teachers following or subverting the curriculum materials*. In this framework, researchers took the curriculum materials as a starting point and then considered the degree to which teachers followed or subverted them. These researchers believed that fidelity between the intended curriculum and the enacted curriculum was achievable and was the primary goal of implementation. Thus, these researchers often focused on how curriculum designers could provide close guidance to teachers. The second framework was *teachers drawing upon and incorporating the curriculum materials*. In this framework, it is the classroom practice, not the curriculum materials, which are taken as the starting point. These researchers argued that the curriculum materials were only one of many resources the teacher used for the learning environment. These researchers viewed the curriculum materials as useful tools, but not as the sole force influencing classroom practice. The third framework was *teachers' interpretations of the curriculum materials*. In this framework, researchers investigated the frames that teachers used to analyze and interpret the curriculum materials. These researchers assumed that fidelity between the planned and enacted curriculum was not the primary goal of implementation, and was also not possible because teachers interpret the materials in light of their own personal beliefs and experiences. These researchers, therefore, studied teachers' interpretations of curriculum materials, the factors which

influenced them, and the resulting classroom practices. The fourth framework, and closely related to the third, was *teachers' participation with the curriculum materials*. In this framework, researchers focused on the interactions between the curriculum materials, the teachers and the students and viewed this interaction as collaboration. In this framework, researchers give agency to the curriculum materials by describing how they interact with teachers and students. For my study, I adopted the fourth conception of curriculum use because it allowed me to study the dynamics between the laboratory materials, the professor, the TAs, and the students. Together, Brown (2009) and Remillard (2007) provided the teacher-curriculum materials framework I used for this study. The teachers, in context of my study, were Richard (the professor) and the TAs (physics doctoral students). It is important to note that the curriculum materials Brown (2009) and Remillard (2007) surveyed were educative for students. The recent work of Krajcik and others (e.g. Schneider & Krajcik, 2002; Davis & Krajcik, 2005), in comparison, have focused on transforming these materials in order to promote the development of teacher learning as well.

Curriculum materials have traditionally been designed to support student learning. However, in light of the previous discussion, adopting curriculum materials does not guarantee instructional change. As a result, some researchers theorized how to support teacher learning through the development of curriculum materials that are educative for teachers (Ball & Cohen, 1996). Educative curriculum materials, as they have been called, are curriculum materials that are designed to support teacher learning, as teachers use the materials to support student learning (Schneider & Krajcik, 2002). This support is crucial for the success of student-centered curriculum materials because these materials often entail new representations of content and new teaching strategies to support student construction of knowledge (Schneider & Krajcik, 2002). Therefore, teachers unaccustomed to designing these types of learning environments are best viewed as novice teachers (Davis & Krajcik,

2005). As such, Schneider and Krajcik (2002) argued that educative curriculum materials can have a role in developing the teacher from novice to expert teacher. Davis and Krajcik (2005), building on earlier work (Shulman, 1986; Ball & Cohen, 1996; Schneider & Krajcik, 2002) presented a set of design heuristics (guidelines) intended to facilitate the construction of educative curriculum materials. The full list and description of these design heuristics is presented in Appendix A.

These design heuristics are framed within the context of three domains of teacher knowledge—subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge (Shulman, 1986). Pedagogical knowledge refers to general teaching strategies while pedagogical content knowledge refers to specific teaching strategies which are highly domain and context specific. Davis and Krajcik's (2005) design heuristics give advice for constructing educative curriculum materials which support teacher learning in each of these three domains, as teachers use the materials to support student learning. Part of my study investigated the degree to which the adopted curriculum materials were educative for the professor and TAs.

In summary, I used this teacher-curriculum materials framework as a way to understand how Richard used the laboratory materials to design the laboratory learning environment and how the TAs and students interacted with those materials in the astronomy laboratory learning environment. This framework led directly to the construction of my first research question.

### **Terminology and definitions.**

- *Curriculum* or *learning environment* is meant to describe any general school environment composed of teachers, students, and curriculum materials. Learning environment and curriculum, in this dissertation, refer to the same concept.
- *Curriculum materials* are meant to refer to any materials which are adopted, interpreted, and adapted by a teacher.

- *Laboratory materials* are meant to refer to the specific curriculum materials that were adopted for this particular astronomy laboratory learning environment.
- *Teacher* is meant to refer to any teacher in K-16 education. When referring to particular grade levels, I use the terms *high school teacher*, *professor*, or *TA*.

**Purpose of this study.**

The purpose of this study was to investigate the design and enactment of an inquiry-based undergraduate astronomy laboratory learning environment and to investigate the impact of that astronomy laboratory learning environment on students' understandings of NOSI. I framed this study within a qualitative research paradigm where I relied heavily on non-participant observations of the learning environment as well as semi-structured interviews with Richard and two TA-participants. I used qualitative coding procedures to inductively and deductively respond to my two research questions. In the next chapter, I survey the relevant literature to make sense of the need for my study.

## Chapter 2: Review of the Literature

In this literature review, I describe and analyze the empirical research related to several aspects of inquiry-based learning environments. In the first section, I describe how inquiry is conceptualized in the science education community. In the second section, I examine empirical research related to inquiry-based learning environments in the specific context of undergraduate science education. In the third section, I describe the learning opportunities of the college science laboratory and describe the basic characteristics of *Engaging in Astronomical Inquiry* (Slater et al., 2010), the laboratory materials adopted for use in this study. In the fourth section, I survey the nature and impact of general reform efforts in the physics and astronomy education community. In the fifth and final section, I synthesize the previous sections to make sense of the context and need for this study.

### **Inquiry in science education**

In this section, I describe how science educators, based on scholarship from fields such as philosophy of science, history of science, and sociology of science, have conceptualized inquiry. In general there are three different ways in which inquiry has been conceptualized: inquiry as scientific process, inquiry as students' skills, and inquiry as pedagogical strategy.

#### **Inquiry as scientific process.**

The first way inquiry is conceptualized may be understood by considering the question: *How do scientists do their work?* Contrary to the popular, and ultimately mistaken, belief that scientists follow the so-called scientific method (where scientists make observations, formulate a hypothesis, set up a scientific experiment, collect data, and analyze and interpret the results to arrive at secure knowledge), real science is not so black and white. Several reform documents (AAAS, 1989, 1993; NRC, 1996, 2000, 2012) informed by philosophers of science, sociologists of science, historians of

science, science educators, and scientists themselves, have addressed this issue. *Science for all Americans* (AAAS, 1989) states:

Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypotheses and theories, the kinds of logic used, and much more. Nevertheless, scientists differ greatly from one another in what phenomena they investigate and in how they go about their work; in the reliance they place on historical data or on experimental findings and on qualitative or quantitative methods; in their recourse to fundamental principles; and in how much they draw on the findings of other sciences. (p. 3)

It is clear from this statement that scientists cannot simply be described as following a set of steps that, if followed, lead to secure knowledge. Similar language regarding the idea that there is no single scientific method is encapsulated in the following passage from the *Benchmarks for Science Literacy* (AAAS, 1993):

Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of "making a great many careful observations and then organizing them." It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as "the scientific method." It is much more than just "doing experiments," and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realize, yet sooner or later strict logic and empirical evidence must have their day. Individual investigators working alone sometimes make great discoveries, but the steady advancement of science depends on the enterprise as a whole. (p. 9)

Similar statements are found in the *National Science Education Standards* (NRC, 1996) and *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012).

Others have described in more detail what students should be able to recognize if they possess an understanding of the nature of scientific inquiry [NOSI]. Schwartz, Lederman, and Lederman (2008), based on scholarship from multiple fields, argue that an *understanding of NOSI* entails recognizing the following: (1) questions guide scientific investigations, (2) scientists use different methods to investigate phenomena, (3) scientists conduct their investigations for different purposes, (4) scientific explanations are logically consistent arguments which emphasize evidence, (5) scientists have different ways to recognize and handle anomalous data, (6) scientists collect data and construct evidence from data, and (7) scientific inquiry is embedded within a community which has established standards and practices. Studies have investigated students' understanding of NOSI in terms of these seven NOSI tenets, and many of the authors are Lederman's former students (e.g. Schwartz, 2011; Schwartz, 2007; Lederman & Lederman, 2004; Schwartz, Westerlund, Garcia, & Taylor, 2010).

Collectively, these statements mark the first way in which the construct inquiry is conceptualized: Inquiry refers to the various methods and arguments advanced by scientists as they investigate questions pertaining to the natural world and understanding these processes is a learning goal for science students. Students should learn about the *nature of scientific inquiry* [NOSI].

### **Inquiry as student skills.**

The second way inquiry is conceptualized may be understood by considering the question *What skills should students develop in a science course?* In this sense, inquiry represents students' skills in a science course. Benchmarks for Science Literacy (AAAS, 1993) frame this idea in the following manner:

Another, more ambitious step is to introduce student investigations that more closely approximate sound science. Such investigations should become more ambitious and more sophisticated. Before graduating from high school, students working individually or in teams should design and carry out at least one major investigation. They should frame the question, design the approach, estimate the time and costs involved, calibrate the instruments, conduct trial runs, write a report, and finally, respond to criticism. (p. 9)

The argument behind developing students' inquiry skills by modeling what real scientists do is that students will best learn science if they learn using a reasonable facsimile of the processes that real scientists follow (Flick & Lederman, 2006). The National Science Education Standards (NRC, 1996) also describe inquiry as the development of students' skills:

The Standards call for more than "science as process," in which students learn such skills as observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills. (p. 2)

This statement makes it clear that part of being a science student entails developing and using skills necessary to support inquiry. Others have described in detail the skills that students should develop and have labeled this as "classroom inquiry" (NRC, 2000). According to the NRC's (2000, p. 29) document, students are engaged in inquiry to the extent that they are engaged, in some way, in the following: (1) the learner is engaged in scientifically oriented questions, (2) the learner gives priority to evidence, (3) the learner formulates explanations from evidence, (4) the learner connects



explanations to scientific knowledge, and (5) the learner communicates and justifies explanations.

This marks the second way in which the construct inquiry is conceptualized: Inquiry refers to a set of skills science students should develop and use in science courses and also represents a goal for science students. Students should develop the ability to *engage in scientific inquiry*.

### **Inquiry as pedagogical strategy.**

The third way inquiry is conceptualized may be understood by considering the question *How should teachers teach science to their students?* In answering this question, inquiry is referred to as a pedagogical strategy science teachers can employ in their classrooms. Although reform documents do not provide specific prescriptions on how to set up learning environments to maximize the probability of student success, they do provide the initial impetus for changing the way science courses are taught.

In *Science for all Americans* (AAAS, 1989), the authors offer general advice to science teachers by recommending that lessons begin by engaging students with questions about nature, encourage active and collaborative engagement, concentrating on the collection and the use of evidence, and not separating the “knowing” from the “finding out.” This mode of teaching, exemplified in the popular Learning Cycle Model (Lawson, 1979) and 5E Model (Bybee, 1997), means that prior to formal lectures that introduce science concepts, students may benefit from having an opportunity to explore the concepts on their own through hands-on, minds-on activities. Some have argued that the science laboratory may be the ideal venue for this type of pedagogical strategy. In fact, Benchmarks for Science Literacy (AAAS, 1993) argue this at quite some length:

If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate. But that will require recasting typical school laboratory work. The usual high-school science

"experiment" is unlike the real thing: The question to be investigated is decided by the teacher, not the investigators; what apparatus to use, what data to collect, and how to organize the data are also decided by the teacher (or the lab manual); time is not made available for repetitions or, when things are not working out, for revising the experiment; the results are not presented to other investigators for criticism; and, to top it off, the correct answer is known ahead of time. (p. 8)

This statement implies that teachers should set up their laboratory learning environments in a way that students are free to explore concepts more deeply and to have opportunities to use and develop the skills necessary to engage in inquiry rather than the all-too-common cookbook activities that science students of all levels are typically engaged in. Taken collectively, these statements mark the third, and final, way in which inquiry is conceptualized: Inquiry refers to a *pedagogical strategy* teachers may use to promote learning in their classrooms.

### **Summary.**

This descriptive analysis of national reform documents suggests that there are at least three definitions ascribed to the term inquiry: (1) knowledge of how scientists do their work (*understanding of NOSI*), (2) skills developed and used by science students (*engaging in inquiry*), and (3) *pedagogical strategies* used by science teachers (*teaching science as inquiry*). This framework for understanding inquiry is similar to a framework described in a recent meta-analysis that investigated the impact of inquiry science instruction on K-12 student outcomes (Minner, Levy, & Century, 2010). They suggest that inquiry has been viewed in the three following ways:

The term inquiry has figured prominently in science education, yet it refers to at least three distinct categories of activities—what scientists do (e.g., conducting investigations using scientific methods), how students learn (e.g., actively inquiring through thinking and doing

into a phenomena or problem, often mirroring the processes used by scientists), and a pedagogical approach that teachers employ (e.g., designing or using curricula that allow for extended investigations). (p. 476)

These three categories are essentially synonymous with the three I previously examined. There are three final noteworthy things I wish to bring to the reader's attention before moving on to the next section of this literature review.

First, in my study, I focused most heavily on categories one and two; students' *understanding of NOSI* and students' ability to *engage in scientific inquiry*, respectively. This distinction is extremely important and yet, as I will argue, is often ignored in the empirical studies I located. As I will argue, without knowing how inquiry was conceptualized in these studies, transfer of the research findings into different contexts becomes problematic.

Second, an additional reason the distinction between *understanding of NOSI* and *engaging in inquiry* is important is that there is no guarantee that students engaged in inquiry will develop improved understandings of NOSI. This can be observed by comparing the seven NOSI tenets to the five inquiry skills, as previously discussed. There is no reason to think that just because students are engaged, in some way, with any or all of the five inquiry skills described that they will therefore develop an understanding of any or all of the seven NOSI tenets. Regardless, there is no evidence, to my knowledge, to support the claim that these learning goals will co-develop. I urge the reader to keep this distinction in mind throughout the remainder of this dissertation, as I will refer to this distinction often.

Third, and as I alluded to previously, inquiry-based learning environments are only one particular type of student-centered learning environments. Student-centered learning environments are any learning environment where students are actively and cognitively engaged (Land & Hannifin,

2000). There are many different types of student-centered learning environments including problem-based learning, project-based learning, inquiry-based learning, model-based learning, peer-instruction, interactive-lecturing, and lecture-tutorials (Jonassen & Land, 2000; Mazur, 1997; McDermott & Shafer, 2002). Although each of these learning environments is unique, each of these instructional strategies promotes some form of active-engagement (Henderson, Dancy, & Niewiadomska-Bugja, 2012). For example, inquiry-based learning environments promote active-engagement through student construction of research questions, data collection and analysis procedures, and evidence-based conclusions. I urge the reader to attempt to keep this distinction between inquiry-based learning environments and student-centered learning environments in mind during the remaining sections of the literature review.

### **Research on Scientific Inquiry in Undergraduate Education**

This portion of the literature review contains four sections. In the first section, I describe the article selection process. In the second section, I describe research related to professors and inquiry-based learning environments. In the third section, I describe research related to TAs and inquiry-based learning environments. In the fourth section, I describe research related to undergraduate students and inquiry-based learning environments. This particular separation of the literature review is somewhat arbitrary in that different partitioning is possible. However, as mentioned previously, the context of this study was an undergraduate astronomy course taught by a beginning professor and an accompanying lab supervised by TAs. More specifically, I sought to understand the interactions between the curriculum materials and all participants. Therefore, I separated my literature review by participant as opposed to other categorizations.

### **Selection and analysis process.**

The procedure I followed in selecting articles and books for this literature review was the following:

- (1) Articles were published in peer-reviewed scholarly journals or by national science education organizations.
- (2) Priority was given to articles where empirical research was conducted.
- (3) Participants in the studies were professors, TAs, or college students. Students' year and major did not matter.
- (4) Articles investigated some aspect of an inquiry-based learning environment in the lecture or laboratory. This included, but was not limited to professors', TAs', or students' perceptions and/or experiences within inquiry-based learning environments, the impact of inquiry-based learning environments on various measured outcomes, and any type of professional development professors or TAs engaged in, if that professional development was aimed at helping to support inquiry-based learning environments.

With these three general selection criteria, several searches were made in various databases. First, keywords (e.g. inquiry, college, undergraduate, TA, professor) were entered into the advanced search databases of several scholarly journals including: *Journal of Research in Science Teaching*, *The Science Teacher*, *Science Education*, *Science & Education*, *International Journal of Science Education*, and *Journal of College Science Teaching*, along with several other discipline-specific journals such as *Journal of Geoscience Education* and *The Physics Teacher*. Additionally, a secondary search was conducted using the *ERIC* database to find additional articles not found using the first method. I also conducted a forward reference-check. A forward reference-check answers the question *Who has cited this article?* Google Scholar was selected as the database for this forward

reference-check because of its user-friendly interface. In the next three sections, I synthesize the results of professors, TAs, and students' experiences in inquiry-based learning environments. This analysis excluded studies of general student-centered learning environments for the reasons previously discussed. Instead, I save discussion of these studies for a later section where I discuss the impact of general reform efforts in physics and astronomy education.

### **College science professors and inquiry.**

There are very few empirical studies that investigated professors' attempts to support inquiry-based learning environments. Only four such articles were located and these studies did not involve the laboratory learning environment (Brown, Abell, Demir & Schmidt, 2006; Rogers & Abell, 2008; Cheung, 2007; Ash, Brown, Kluger-Bell, and Hunter, 2009). This alone provides support for the need for more studies which document the implementation of inquiry-based learning environments in undergraduate science education, particularly in the science laboratory. Additionally, I will argue that this research, while useful in some respects, fails to address how the learning environments were designed and fails to adequately describe the type of inquiry that was the focus of the learning environment (understanding of NOSI vs. engaging in inquiry vs. inquiry as pedagogy). As I mentioned previously, such distinctions are important. Finally, no studies were located in the physics and astronomy education literature which investigated professors' understanding of, or experiences with, the specific context of inquiry-based learning environments. Instead, the literature in the physics and astronomy education community focuses primarily on professors' uptake, and sustained use, of general student-centered learning environments used during lectures. I save this literature for the fourth section dealing with innovative physics and astronomy curricula. I now discuss the four studies which did investigate professors' understanding of, and experiences in, inquiry-based learning environments.

Brown et al. (2006) studied 19 science professors' beliefs about students' abilities to engage in scientific inquiry. The professors for their study were drawn from a variety of college settings including public research universities, public master's degree-granting universities, small private liberal arts colleges, and 2-year community colleges. From an inductive analysis of semistructured interviews, the researchers found that most professors believed that student engagement with inquiry was appropriate only for upper-level college science students. The professors believed that an inquiry-based learning environment was characterized as completely student-driven and without teacher guidance. In their view, these learning environments entailed students generating questions and planning and carrying out investigations on their own, without the assistance of the teacher. Brown et al. (2006) argued that this incomplete view of inquiry as being an all-or-nothing, student-driven activity was the largest factor explaining professors' beliefs that inquiry-based learning environments were largely unstructured and appropriate only for upper-level college science students. It is interesting to note that although professors were from a variety of disciplines and had varying amounts of college teaching experience, they generally all held incomplete views of inquiry-based learning environments. This may suggest that teaching experience alone is insufficient in developing college teachers' understanding of inquiry. The remaining studies investigated professors' implementation of inquiry-based learning environments.

Rogers and Abell (2008) studied the alignment between two co-professors' stated course goals and students' experiences in an inquiry-based undergraduate, interdisciplinary science course for nonscience majors. Unfortunately, the authors do not explicitly address which type of inquiry they are referring to (skills or NOSI or pedagogy). Through an inductive analysis of fieldnotes, semistructured interviews with the professors and students, and course artifacts, the researchers found consistency between the stated goals of the course and the experiences of students. The researchers

argued that the professors' described course goals were being met based on analysis of student interview data. Those course goals were to teach students how scientists do science and to teach students fundamental science concepts that are connected across different science disciplines. From their main goals, it is perhaps safe to assume that their view of inquiry refers to students' abilities to engage in inquiry, though no such explicit description can be found. The authors described their study as evidence that inquiry-based learning environments can be realized in undergraduate science education and further suggested that attaining close alignment between course goals, teaching methods, and assessment procedures is crucial for any successful implementation of inquiry. In science education courses, alignment between course goals, instructional methods, and assessments is a fundamental requirement (Bybee, Trowbridge, & Powell, 2007).

Cheung (2007) used open-ended questionnaires to investigate seven professors' concerns about implementing inquiry-based learning environments in their classrooms and then developed teaching strategies to alleviate their biggest concerns. From his analysis, Cheung reported that professors' three main concerns were lack of class time, lack of effective curriculum materials, and large class sizes. To help professors cope with their concerns, Cheung developed teaching strategies including the use of guided inquiry rather than open inquiry, ten examples of inquiry-based curriculum materials based on his own published work, and inclusion of student oral presentations as a key component of the inquiry process. Cheung reported one professor's successful experience implementing a small portion of one of these ten examples with his students. Cheung recommended that professional development should develop professors' conceptions of the difference between open and guided inquiry approaches, should develop professors' questioning strategies, and should convince them to require their students to present their findings orally in front of their peers. Unfortunately, we are not provided with an adequate description of the learning environment and



hence are left uninformed of the type of inquiry that the learning environment stressed (understanding of NOSI vs engaging in inquiry vs pedagogy).

Ash et al. (2009) studied professors' changing practices and attitudes concerning college science teaching after participating in a long-term, inquiry-based teaching professional development program while still able to maintain an ongoing commitment to their personal science research agendas. Through an inductive analysis of observational notes, video recordings of activities professors engaged in, and semistructured interviews, the authors reported that these professors' professional identities began to change over the course of the five-year program. The professors, who possessed no prior experience with inquiry-based teaching strategies, became increasingly interested in reflecting on their own teaching, became aware of their teaching philosophies and how those philosophies were changing, became aware of their focus shifting away from teacher-actions towards student-behaviors, and eventually recognized the major differences between lecture-based learning environments and inquiry-based learning environments. Their study may suggest that identity change is a necessary condition of transformation professors must go through in order to become successful inquiry teachers, though again, we are not provided with sufficient description of the type of inquiry the learning environment stressed (understanding of NOSI or inquiry skills or pedagogy).

To summarize, empirical studies of professors' understanding or implementation of inquiry-based learning environments is extremely scant. Moreover, as illuminating as these studies may be, their significance is limited in light of my second theoretical framework (teacher-curriculum materials framework). These studies do not describe the design process that led to the enactment of the inquiry-based learning environment. Therefore, we do not know what personal, contextual, and idiosyncratic effects may have taken place that shaped the resulting inquiry-based learning environment. This makes transfer of these findings to new contexts problematic. Moreover, with the

exception of the Brown et al. (2008) study, none of the three remaining studies explicitly defined what was meant by an “inquiry-based” learning environment. The reader cannot know whether the classroom activities focused on students learning *about NOSI* or focused on students *engaging in scientific inquiry* or *inquiry as pedagogy* or something else entirely. These distinctions are important because without inquiry being operationalized, readers cannot develop shared understandings, making transfer of findings to different contexts even more challenging. In this particular case, these distinctions are even more important because qualitative studies generalize through context-transfer and without knowledge of what type of inquiry-based learning environment was constructed, it is impossible for others to attempt to construct similar environments.

Further, as encouraging as the Ash et al., (2009) and Cheung (2007) findings are with respect to the effect professional development can have on professors’ identities, not all professors possess the time and energy (or desire) to self-enroll into these professional development workshops. If workshops are not a viable avenue for professors to take, then the implications of these research findings appear limited.

An additional limitation of current research is that none of the studies provided any evidence of students’ learning to engage in scientific inquiry, learning about NOSI or even learning of science concepts. Instead, these studies focused almost exclusively on the experiences and beliefs of the professors. Of course, no study can possibly investigate every facet of a particular learning environment, but it would be difficult to convince professors to dedicate time, energy, and resources in the construction of inquiry-based learning environments if students do not increase understandings in one of these areas. Further, we do not know if professors adopted and used curriculum materials as part of the learning environment. If curriculum materials were adopted for these studies, we have no

information on the nature of the design process that led to the construction of those materials, nor do we know what idiosyncratic effects found their way into the specific learning environment studied.

With these considerations in mind, I argue that given the dearth of empirical research pertaining to professors' implementation of inquiry-based learning environments, and considering the lack of description of the process that led to the design of those inquiry-based learning environments, and especially considering the lack of a clear description of the type of inquiry that was stressed (understanding of NOSI versus inquiry skills), research needs to focus more on the design and enactment of inquiry-based learning environments and the kinds of factors professors consider during this process. My study partially fills this gap.

### **Teaching Assistants and Inquiry**

Empirical research on TAs' understanding or implementation of inquiry-based learning environments was also fairly limited. This, again, provides support for studies which document the implementation of inquiry-based learning environments in college science classrooms. No studies were located in the physics and astronomy education community which investigated TAs' understanding of, and experiences in, the specific context of inquiry-based learning environments. Existing research focuses primarily on TAs' beliefs about and struggles with general, student-centered teaching strategies used during lectures and recitations. I save this literature for the fourth section dealing with innovative physics and astronomy curricula. Below I describe the studies which investigated TAs' understanding of and experiences in, inquiry-based learning environments and then draw implications from those studies.

Roehrig, Luft, Kurdziel, and Turner (2003) used semistructured interviews and classroom observations to examine how six chemistry TAs taught an inquiry-based laboratory at a research university. The course was described as developing students' inquiry skills. Through an inductive

analysis of semistructured interviews and non-participant observations, the researchers reported that TAs' prior experiences as students affected their instructional decisions, that TAs did not have the skills necessary to support an inquiry-based learning environment, and that TAs possessed naïve conceptions of how students learn. They suggested that unless TAs come to value inquiry-based learning environments, they are unlikely to be able to effectively supervise these environments. They also suggested that weekly TA meetings should be used to discuss TA pedagogical strategies and to communicate and model acceptable behaviors that TAs are expected to replicate in their classrooms.

Volkman, Abell, and Zgagacz (2005) studied the teaching orientations (Magnusson, Krajcik, & Borko, 1999) of a TA who co-taught an undergraduate inquiry-based physics course for elementary education majors. Unfortunately, it is unclear which type of inquiry is stressed in this learning environment (understanding of NOSI vs. engaging in inquiry vs. inquiry as pedagogy). Through an inductive analysis of fieldnotes, semistructured interviews, and the TA's reflective journal, the researchers generated several claims regarding the TA's teaching orientation. The TA was described as possessing the traditional view that the purpose of teaching was to transmit knowledge to the students. Because of this, the authors argued, conflicts arose between the TA and the professor of the course, who did not share this belief. The authors also described the professor-TA conflict in terms of the role of assessment. The TA believed the purpose of assessment was to "weed out" the weaker students, while the professor believed assessment was to be used to understand the current knowledge of the student in order to understand where they needed assistance. The authors asserted that all conflicts between the professor and TA arose because of their differing views of the role and purpose of teaching, learning, and assessment. Further, the authors argued that the TA's beliefs translated directly into classroom practice on the basis that the TA wished to immediately give answers to students' questions and desired to correct students' inaccurate work before they pressed on

during activities. The authors stated that unless TAs value inquiry-based learning environments, it is unlikely they can effectively support inquiry-based learning environments. Further, and similar to Rogers and Abell (2008), these authors argued that close alignment between the learning goals, the teaching methods, and assessment procedures was a necessary condition of any effective learning environment.

Narayan (2010) studied the verbal discourse practices in traditional and inquiry-based biology labs for nonscience majors in a large teaching-focused university. This course was described as developing students' understanding of biology concepts as well as improving students' general inquiry skills. Participants in this study included a select sample of 15 undergraduate students as well as four TAs. Through an inductive analysis of video-recorded labs, audio-recorded interactions between TAs and students, and semistructured interviews, the researchers found that the nature of TA-student discourse (what was discussed, the frequency, duration, etc.) was best explained by the *modus operandi* (pattern of behavior) of the TA and the structure of the lab activities. For example, one TA was observed to simply hand out labs and then sit in the back of the room waiting for questions. In this lab, the TA-student interactions focused on procedural issues and obtaining the correct answers and the number of verbal interactions between students decreased. In contrast, another TA was active within lab, engaged students even when they did not have questions, and went as far as to mandate end-of-lab discussions. In this lab, TA-student interactions focused on conceptual understanding of content and deeper understanding of research procedures and the number of verbal interactions between students increased. Narayan does not inform the reader from which number the verbal interactions decreased/increased from, nor which number the verbal interactions increased/decreased to and instead defers this quantitative research to another time. Narayan summarized his study by stating "a greater volume of student discourse and more variation was

exhibited in the inquiry-based than the traditionally-based laboratories” (p. 614). Because the TA is often the sole interface between science content and the undergraduate student, at least in the laboratory, Narayan emphasized that the TA-factor should not be overlooked during the development or enactment of undergraduate science curricula.

Gormally, Brickman, Hallar, and Armstrong (2011) studied challenges associated with developing and implementing student-centered, guided-inquiry laboratories in an undergraduate biology classroom. Part of this research entailed investigating the experiences of TAs as they taught inquiry-based labs. Unfortunately, we are not provided with a sufficient description of the type of inquiry that is stressed in the learning environment (understanding of NOSI vs. engaging in inquiry vs. inquiry as pedagogy). Through an inductive analysis of data consisting of semistructured interviews and observations of TAs, the researchers made several claims. First, many TAs were initially hesitant and even resistant to changing their teaching styles to accommodate an inquiry-based approach. Second, by the end of the semester most TAs’ views had shifted to not only accommodate an inquiry-based teaching method, but also to appreciate the inquiry-based teaching method. Third, the most common problem TAs experienced involved helping students through questioning as opposed to giving direct instructions. The weekly TA meetings consisted of emphasizing the use of effective questioning techniques to redirect the thinking and learning back to the students as well as observation and reflection of videotaped inquiry and traditional lessons. Although TAs believed this training was more time consuming than they were used to, they acknowledged that the training improved their teaching skills. In closing, the researchers remarked that constructing an inquiry-based learning environment required not only a substantial investment in curriculum development but also significant investment in TA training to facilitate the shift in TA instructional practices. This study suggests that simply adopting curriculum materials that are

believed to be inquiry-based may not be sufficient to enact an inquiry-based curriculum. That is, the TA appears to be a factor in the successful construction of inquiry-based learning environments. This is consistent with Remillard (2007) and Brown (2009) which were discussed in the theoretical framework section.

Seung, Bryan, & Haugan (2012) investigated the pedagogical content knowledge [PCK] that physics TAs developed in the context of teaching a new inquiry-based physics curriculum. Five TAs participated in a four-week summer TA workshop which met for five hours per day, five days each week. TAs learned about research-based pedagogical strategies and engaged in many problem-solving activities which mirrored the activities their students would be engaged in. Through analysis of multiple data sources including semistructured interviews, TAs' written reflections, video-recorded observations, and field notes, the authors described how three (out of the five) components of TAs' PCK developed as a result of their participation in the summer workshop as well as secondarily through reflection of their teaching practices. Specifically, they found that TAs developed knowledge of the goals of the curriculum, of instructional strategies, and of students' learning. The authors suggested that simply understanding the content one teaches (in this case, physics content) was "not sufficient to be an effective instructor" (p. 472). They also argued that knowledge of curriculum goals needs to be central in any TA training program because, in their study, TAs' knowledge of curriculum goals most directly affected their observed classroom decisions.

To summarize, the empirical literature pertaining to TAs' understanding or implementation of inquiry is also scant. However, this literature suggests that unless TAs develop and understanding and appreciation of inquiry, they are unlikely to become effective inquiry teachers. TAs with traditional (transmissionist) teaching beliefs encounter conflicts while facilitating inquiry-based learning environments. These studies suggest that TA training should focus on facilitating a shift in

TAs' instructional practices and help TAs become reflective on their changing teaching practices. There are several limitations of this research. These studies do not describe the design process that led to the enactment of the inquiry-based learning environment. Therefore, we do not know what personal, contextual, and idiosyncratic effects may have taken place that shaped the enacted curriculum. This makes transfer of findings to new contexts problematic. Further, although professional development may prove powerful for developing the pedagogies of TAs, this route is likely not feasible if professors with no formal educational training are to be the leaders of such professional development. Professional development offered by science professors is different compared to professional development offered by professional science educators (Gardner & Jones, 2011). Therefore, it seems unlikely that professional development is a viable route of instructional change in departments which do not have members or professional connections with individuals knowledgeable of science education research.

A limitation of this research is the lack of definition of the term inquiry as used in the studies. As with the literature pertaining to professors, some of these studies did not describe the type of inquiry stressed in the learning environment. As discussed earlier, these distinctions are important and in these studies we simply do not know because it is not described. Further, we are not typically provided with any evidence of student learning. As suggested in the previous section, if we wish to convince professors (or TAs) to change their teaching practices, evidence of student learning would be useful. We do not know the extent to which adopted curriculum materials may have shaped the enacted curriculum. I suggest that given the dearth of empirical research pertaining to TAs' implementation of inquiry in the classroom, and considering the lack of description of the process that led to the design of those inquiry-based learning environments, research should focus on the



design and enactment of inquiry-based curricula and the role that the TA plays during this process. My study, in part, addresses this gap.

### **Undergraduate Students and Inquiry**

This section serves two purposes. First, I describe the research related to undergraduate students and inquiry-based learning environments. Second, I survey the available studies which specifically investigated students' understanding of NOSI.

#### ***Students and inquiry-based learning environments.***

The number of studies investigating some aspect of inquiry and undergraduate science students was slightly higher than for professors and TAs, however there are several caveats to this claim. The vast majority of these studies did *not* investigate the impact of inquiry-based learning environments on students' understanding of NOSI or on the development of inquiry skills. Instead, these studies investigated the connection between the inquiry-based learning environments and students' improved understanding of content. Other studies investigated the experiences of students in inquiry-based learning environments. Though this information is useful, the development of content knowledge was *not* the focus of the adopted laboratory materials in this study (Lyons, 2011; Sibbernsen, 2010). Regardless, and for sake of completeness, I describe these studies and very carefully draw implications from them.

Wallace, Tsoi, Calkin, and Darley (2003) studied the lived experience of five nonscience students as they participated in an inquiry-based biology laboratory. Through an inductive analysis of multiple semistructured interviews with each student, the researchers found that students' possessed learning beliefs that were either traditional or constructivist, that older students held learning beliefs that aligned more with constructivism, that students with constructivist learning beliefs developed more robust conceptual understandings of biological concepts, and that students with traditional, rote

learning strategies did not fare well in the inquiry environment. This finding is significant because if students' learning beliefs do not align with the learning beliefs of the instructor then a conflict may arise. Additionally, instructors may want to help students modify their learning beliefs in order to facilitate deeper conceptual understandings in student-centered learning environments.

Duran, McArthur, and Van Hook (2004) studied preservice elementary students' perceptions of an inquiry physics course. Through an inductive analysis of focus-group interviews, they identified four main themes. First, students were often frustrated being a student in an inquiry course because they were used to being given the answers they sought rather than constructing them. Second, although students were frustrated at first, many believed that it was a valuable learning experience. Third, students felt that the workload in an inquiry-based course was greater than the workload in a traditional-lecture course. And fourth, although students acknowledged the greater workload, they believed that inquiry-based teaching methods would better meet their needs as future teachers. Although preservice teachers initially possessed reservations regarding inquiry teaching, they eventually came to embrace it. This is significant because preservice teachers are the future teachers of our next generation of students. This study demonstrates that we can effectively instill within preservice teachers the value of inquiry-based learning environments. However, we do not know whether these preservice teachers' practices will ultimately reflect their understandings or values when they begin teaching.

Rissing and Cogan (2009) compared the effect of an inquiry and traditional biology lab courses on students' conceptual understandings of biological content. The stated goal of the inquiry course (p. 59) was to teach science in the manner that science is actually conducted (engaging in inquiry), while the goal of the traditional course was simply to communicate the content through lecturing. Through a statistical analysis of students' responses to content and attitude instruments of

the authors design, the researchers found that students who completed the inquiry labs showed significant improvement in both content and attitude over students in the traditional labs. Their study demonstrates that inquiry learning environments may support students' understanding of concepts better than traditional learning environments can.

Derting and Ebert-May (2010) investigated the effect of an inquiry-based curriculum on 84 students' long-term understanding of biological concepts and of biology as a process of inquiry. Following a statistical analysis of students' responses to two assessments given over a five-year period, the researchers found that students described their inquiry-learning experiences as generally positive. They also found that completion of the curricula was associated with long-term change in understandings of biology as a process of inquiry. This study suggests that intense and prolonged exposure to learner-centered inquiry environments can enhance students' understanding of biological concepts and their understandings of the nature of scientific inquiry.

Krystyniak and Keikkinen (2007) compared the verbal interactions among six student lab teams with their instructor over three inquiry-based laboratory investigations and two traditional laboratory investigations. Through an inductive analysis of audiotaped recordings of verbal interactions between student teams and instructors, the researchers found that verbal interactions between student teams and the instructors were fewer during inquiry investigations as compared to the traditional investigations. They also reported that verbal interactions among student groups themselves were fewer during the inquiry-based laboratory activities than during the traditionally-based laboratory activities. Further, student questions in the traditional investigations were mainly procedural and focused on ascertaining correct answers for prescribed tasks and identifying which data to record. In comparison, questions during inquiry investigations were centralized around data analysis, calculations, and conclusions. This study's findings stand in direct contrast to the findings

presented by Narayan (2010). Whereas Narayan found increased student-student and student-TA discourse during inquiry-based laboratory environments, this study reported the exact opposite. Unfortunately, it would be mere speculation to articulate possible reasons for this discrepancy given the lack of adequate descriptions of either learning environments.

In a similar study, Cianciolo, Flory, and Atwell (2006) used an inquiry observation protocol form (IOP) to determine whether inquiry-based biology activities elicited more observed instances of inquiry-behaviors than traditional activities during lectures. The IOP form was modeled after a version of the Reformed Teaching Observation Protocol (RTOP) which defines specific behaviors students are expected to engage in while in inquiry-based learning environments. Each week, five classes were observed using the IOP form. Through their analysis, the researchers determined that students performed more inquiry-type behaviors at higher frequencies during inquiry activities than during the traditional activities. In addition, students in the inquiry activities were more likely to discuss relevant material with each other and listen to other students talk. In the traditional classes, students were more likely to listen to the instructor talk, read class materials or write things down. This study suggests that students engage in higher frequencies of inquiry-like behaviors when they are exposed to an inquiry-based learning environment.

To summarize, the empirical research related to undergraduate students' experiences and performances within inquiry-based learning environments suggest that students may learn to appreciate the shifting roles of students and teachers in these types of learning environments, though not without initial frustration. Some studies suggested that students learn to appreciate the true process of inquiry in their specific scientific discipline in the long term. Evidence also exists that students can learn concepts better in an inquiry-based learning environment and are observed to engage in more inquiry-like behaviors. However, there still exist a number of limitations to these

studies. First, there were no studies which investigated the impact of inquiry-based learning environments on students' understanding of the nature of scientific inquiry. Rather, most studied the lived experience of students in these learning environments, or studied the impact of said learning environments on other student outcomes. Second, there were no studies of inquiry-based astronomy courses or laboratory learning environments, making it hard to predict what one might look like. Third, and just as was described with professors and TAs, none of these studies described the design or implementation phase of the inquiry-based learning environments. We simply do not know what contextual idiosyncrasies are present that may or may not have affected the effectiveness of those environments. Fourth, although some of the studies explicitly define inquiry as student understanding of the nature of scientific inquiry or define it as students engaging in inquiry, other studies did not. Therefore, I suggest that we must first understand how teachers—whether they be professors, high school teachers, or TAs—come to design their inquiry-based learning environments, what factors lead them to this construction, and how it is enacted in practice.

### ***Students' understanding of NOSI.***

As mentioned previously, there is a dearth of research related specifically to students' understanding of NOSI. However, the laboratory materials adopted during this study are described as improving students' understanding of NOSI (Lyons, 2011; Sibbernson, 2010). They are not described as improving students' inquiry skills nor are they described as improving students' mastery of astronomy concepts. In fact, the curriculum designers argue for the efficacy of their laboratory materials based only on students' improved understandings of NOSI (Lyons, 2011; Sibbernson, 2010; Lyons, Slater & Slater, 2011a; Lyons, Slater, & Slater, 2011b). As a result, I investigated the impact of their laboratory materials on students' understanding of NOSI. Therefore, in this section, I overview the typical understandings students have of NOSI. I draw from five sources, all of which

come from the same research group: Schwartz (2011), Schwartz (2007), Schwartz et al. (2008), Lederman and Lederman (2004), and Schwartz et al. (2010). All the following themes come directly from, and only from, these five studies. In order to contextualize typical naïve and informed understanding of NOSI, I present again what an understanding of NOSI entails. Lederman et al. (2008), based on scholarship from multiple fields, described seven NOSI tenets: (1) questions guide scientific investigations, (2) scientists use different methods to investigate phenomena, (3) scientists conduct their investigations for different purposes, (4) scientific explanations are logically consistent arguments which emphasize evidence, (5) scientists have different ways to recognize and handle anomalous data, (6) scientists collect data and construct evidence from data, and (7) scientific inquiry is embedded within a community which has established standards and practices. I now describe typical naïve and informed views of NOSI as described in the studies referenced.

Students with naïve views of NOSI may believe some or all of the following: (a) all scientific data are numbers and statistics, (b) evidence is something presented in a court of law, is the same as data, or proves something to be absolutely true (c) a scientific experiment occurs whenever one investigates or studies some aspect of nature, (d) all scientists use, and must use, the scientific method, (e) do not easily see a connection between data and evidence-based conclusions or their structure, (f) all science is the same across all cultures and science methods provide absolute and irrefutable proof, and (g) scientists do not collect anomalous data. These types of responses stand in stark contrast to the typical responses of students who possess more informed views of NOSI.

Students with informed views of NOSI may believe some or all of the following: (a) data is any type of information collected during an investigation and can be quantitative or qualitative, (b) evidence is data that has been interpreted in light of a question or hypothesis, (c) a scientific experiment is a specific procedural investigation involving the manipulation of variables and the use

of controls, (d) there is no singular scientific method that is both ahistorical and universal, (e) understand the structure and argument of evidence-based conclusions, (f) all science is embedded within a community and culture which can influence the nature of the research conducted, and (g) acceptance of science knowledge comes through peer review, argumentation, soundness of the conclusion, repeatability, etc.

One can easily see the difference between students with naïve views and students with informed views of NOSI. Again, these distinctions are presented by the authors of the studies mentioned at the beginning of this section. It is my hope that this section has provided the reader with an idea of the typical structure of naïve and informed views of NOSI. Additionally, this should help contextualize the answer to the second research question which deals with the impact of this particular laboratory learning environment on student' understanding of NOSI.

### **The College Science Laboratory**

In the following sections, I (a) describe characteristics of the science laboratory that make it an ideal environment for the incorporation of inquiry-based teaching, (b) describe recommended learning goals of the science laboratory, (c) describe the nature of typical college science laboratory experience and (d) describe the laboratory materials that were adopted for the laboratory learning environment during this study.

#### **The unique environment of the science laboratory.**

In the publication called *America's Lab Report* (NRC, 2006), several science education researchers collaborated to address the role of high school science laboratories in the US educational system. They define laboratory experiences in the following way:

Laboratory experiences provide opportunities for students to interact directly with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science. (p. 3)

In a similar way, the *Society for College Science Teachers* (2004) described *college science laboratories* in this way:

Laboratory experiences should be related to, and integrated with, the conceptual flow of every science course. Laboratory activities should feature experimental procedures that require students to think about, select, generate, test, and evaluate the effectiveness of hypotheses and the scope of their results. The laboratory should be considered an opportunity either for discovery or for students to extend and refine their existing conceptual framework. (p. 17)

From these statements, it is clear that student manipulation of actual data is a characteristic of the science laboratory. In addition, students in laboratory environments are expected to “think about, select, generate, test, and evaluate” scientific concepts and theories. Asking questions, designing studies to address questions, and constructing evidence-based explanations are characteristic features of any inquiry-based learning environment. Hence, the science laboratory is appropriately viewed as an ideal venue for inquiry-based learning environments. Large class sizes that professors perceive as a barrier preventing inquiry-based instruction during lectures are no longer an issue because laboratory learning environment typically entail students working together in small, collaborative groups.

### **Learning goals of the science laboratory.**

Various researchers have argued for specific learning goals for the science laboratory learning environment. For example, in a comprehensive review of the science laboratory learning environment



Lunetta, Hofstein, and Clough (2007) suggested that when possible, science laboratory activities should encourage students to exhibit the following behaviors:

- Explicate the principal question(s) they are investigating
- Explicate their relevant prior knowledge
- Employ previously studied science ideas in more complex ways
- Invent laboratory procedures
- Decide what data is relevant and irrelevant; explain what the data means
- Apply mathematical reasoning to problems
- Set goals, make decisions, and assess progress
- Communicate their laboratory work in a clear manner
- Discuss limitations of their sampling, measurement and data
- Make connections between science concepts and everyday phenomena
- Raise new questions suggested by their observations
- Reflect on nature of science issues (p. 423).

Although this list appears daunting, and indeed it may be unrealistic for a single laboratory setting, effective laboratory experiences are generally highly interactive, make explicit students' relevant prior knowledge, encourage active engagement among students and with materials, develop students' inquiry skills and knowledge of the scientific enterprise. In addition, if these student behaviors are the intended outcomes of a successful laboratory environment, then we may state that a science laboratory learning environment is successful to the extent that some or all of these student behaviors are observed.

### **Current status of college science laboratory experiences.**

In this section, I review research on inquiry-based laboratory learning environments. In the previous reviews of TA and student experiences in inquiry-based learning environments, I explored several studies whose context, in fact, was a science laboratory (Roehrig et al., 2003; Narayan, 2010; Gormally et al., 2011; Wallace et al., 2003; Rissing & Cogan, 2009; Krystyniak & Keikkinen, 2007). However, the focus of these studies was not on the nature of the laboratory learning environment, per se. Rather, these studies focuses more generally on TAs' or students' experiences in these learning environments. For example, in most of these studies, we do not know the nature of the laboratory materials nor how they were developed or implemented. Therefore, in this section, I survey what little literature exists to provide the reader with a sense of typical student experiences in the science laboratory learning environment.

Buck, Bretz, and Towns (2008) constructed a rubric to characterize the level of inquiry found in hundreds of undergraduate science laboratory manuals from a variety of disciplines. To characterize the level of inquiry of the laboratory materials, the researchers created a scoring rubric which is shown in Figure 1. The researchers found that of the 386 individual laboratory activities studied, 355 (92%) of them were either confirmation or structured inquiry experiences. This finding is similar to several others for K-12 science laboratories (Tamir & Lunetta, 1981; Glagovich & Swierczynski, 2004). This implies that despite decades of reform recommendations for the science laboratory, very little has changed; the laboratory learning environment remains structured and without room for students' input or creativity in problem solving. This implies that the laboratory materials are not designed to give students' the opportunity to engage in their own thinking surrounding important questions/problems and research procedures.

Characteristic	Confirmation	Structured Inquiry	Guided Inquiry	Open Inquiry	Authentic Inquiry
Problem/Question	Given	Given	Given	Given	<i>Not given</i>
Theory/Background	Given	Given	Given	<i>Not given</i>	<i>Not given</i>
Procedures/Design	Given	Given	Given	<i>Not given</i>	<i>Not given</i>
Results Analysis	Given	Given	<i>Not given</i>	<i>Not given</i>	<i>Not given</i>
Results Communication	Given	<i>Not given</i>	<i>Not given</i>	<i>Not given</i>	<i>Not given</i>
Conclusions	Given	<i>Not given</i>	<i>Not given</i>	<i>Not given</i>	<i>Not given</i>

*Figure 1. Rubric to characterize the level of inquiry in labs.*

Basey, Sackett, and Robinson (2008) examined the impact of six laboratory design characteristics on 84, 400, and 750 college students' attitudes towards science labs in three different first year biology courses at a large, public research university. Through an analysis of two end-of-semester surveys with each of the groups of students, the researchers determined that the perceived excitement of the lab was the most significant factor in impacting student attitudes towards the lab, they the researchers admit that excitement was very subjective and hard to define. The researchers noted that when students described their worst laboratory experience, they also described those experiences as too structured and unexciting. They suggested that highly structured laboratory activities do not support the type of student excitement professors' hope for.

Leonard (1989) published the only located scholarly review of the research on *college* level science laboratory learning and teaching. From his review of 36 research articles, he found that newer and more innovative teaching approaches during the 1980s were more student-centered, were more inductive and required more extensive use of inquiry skills. Through his analysis, he stated that these newer teaching approaches produced significantly greater educational gains than traditional approaches. Moreover, Leonard found that effective laboratory instruction in college science courses

was characterized by having students engaged in science inquiry processes and in the manipulation of experimental tools. It should be noted that others have investigated the science laboratory but these studies typically take place at the K-12 level and not at the college level (Hofstein & Lunetta, 1982; Hofstein & Lunetta, 2004). Moreover, as already noted, these studies generally describe a similar situation—the laboratory learning environment is highly structured and does not promote the learning goals recommended by the science education community.

Collectively, this research suggests that the typical college science laboratory environment is not the learning environment envisioned by science educators. Laboratory activities remain highly structured with a cookbook nature and students' attitude towards the laboratory is discouraging. These conclusions are wholly consistent with results found in K-12 education (NRC, 2006; Hofstein & Lunetta, 1982, 2004). In the next section, I describe and critique the curriculum materials that were adopted in the laboratory learning environment of this study.

### **The laboratory materials adopted for this study.**

In this section, I describe the laboratory materials that Richard adopted for use in the astronomy laboratory learning environment. In addition, I describe the curriculum designer's stated goals of their materials and how these goals were assessed.

The laboratory materials used in the laboratory learning environment for this study were developed by the Center for Astronomy and Physics Education Research [CAPER] team and are called *Engaging in Astronomical Inquiry* (Slater et al., 2010). Their laboratory materials' structure is based on an instructional model they originally created for use during lecture-periods of an astronomy course. Eventually, they modified their original instructional model for use in their undergraduate astronomy laboratory, which typically only meets once per week for two hours. In what follows, I

describe their original instructional model and describe the changes made to their model as they adapted it into their astronomy laboratory.

Slater, Slater, and Shaner (2008) described an inquiry-based instructional approach they labeled as “backwards-faded scaffolding” [hereafter, BFS]. In this approach, students engage in five sequences of inquiry in a specific content area, where each sequence consists of four distinct stages (see Figure 2). The stages are: constructing a research question, constructing a research procedure, collecting and analyzing data and evidence, and constructing an evidence-based conclusion. According to Slater et al. (2008), constructing a viable research question is the most cognitively challenging of the stages. Therefore, in their instructional model, students are not expected to generate their own research question until the fifth and final sequence of inquiry.

Their instructional model uses the concept of cognitive scaffolding to assist students during sequences which are considered to be too cognitively demanding to be completed by students on their own. Their scaffolding model entails providing cognitive support at various stages of sequences of inquiry through the entire process and then subsequently taking steps away, until eventually, students engage in full, open inquiry. It is only in the final sequence that students are asked to generate questions of their own. Figure 2 illustrates their original BFS model.

Their original BFS instructional model depicts five inquiry sequences that the learner is engaged in. Since in their model, the construction of a research question is thought to be the most challenging phase of any sequence, students are supported most heavily during that stage. Students progress through four inquiry sequences prior to generating their own research question. The belief is that the experience of being provided with research questions, within a particular content area, through four complete inquiry sequences, will better equip students to construct their own research questions during the fifth and final inquiry sequence. This instructional model was created to be used

during several, consecutive astronomy lectures, not in a laboratory which typically meet less frequently.

Sequence	Research question	Research procedure	Data and evidence	Conclusion
	Source	source	source	source
1	Teacher	Teacher	Teacher	Teacher
2	Teacher	Teacher	Teacher	<i>Student</i>
3	Teacher	Teacher	<i>Student</i>	<i>Student</i>
4	Teacher	<i>Student</i>	<i>Student</i>	<i>Student</i>
5	<i>Student</i>	<i>Student</i>	<i>Student</i>	<i>Student</i>

*Figure 2. Original BFS instructional model. (Slater et al., 2008, p. 410).*

The CAPER team began exploring ways to use their BFS instructional model in the astronomy laboratory. The structure of their laboratory material's activities differs from their original model as Lyons (2011) described:

In the original BFS format, students are meant to engage in five full sequences of inquiry in one content area. This set of inquiry cycles is intended to take place over several class meetings, a design which is better suited for use in K-12 science classrooms where students meet regularly over the course of one week. Laboratory courses at the college level typically meet only for two hours per week. With this in mind, the CAPER team curriculum developers modified the original BFS format to fit within a two-hour time constraint while preserving the essential sequence and structure of the faded-scaffolds. (p. 53)

The CAPER team adapted their original BFS instructional model to fit within the traditional structure and constraints of the college science laboratory. To do so, they made changes in the nature of their original BFS instructional model. In essence, the CAPER team created two fundamentally different

student laboratory activities: inquiry activities and assessment activities. I will describe each separately.

***BFS inquiry lab structure.***

Figure 3 is the modified BFS instructional model CAPER used for their laboratory inquiry activities (Lyons, 2011, p. 55).

Phase	Research question	Research procedure	Data and evidence	Conclusion
	source	source	source	source
1	X	X	X	X
2	Teacher	Teacher	<i>Student</i>	Teacher
3	Teacher	X	Teacher	<i>Student</i>
4	Teacher	<i>Student</i>	X	X
5	<i>Student</i>	<i>Student</i>	<i>Student</i>	<i>Student</i>

*Figure 3. Modified BFS instructional model for inquiry labs. (Lyons, 2011, p. 56)*

There are several differences between their original instructional model (Figure 2) and their modified instructional model (Figure 3) used in their laboratory. First, they have replaced the term “sequence” with “phase”. Second, the “X” found in certain stages indicates that that particular stage of inquiry is absent from that lab’s phase. For instance, during the first phase of inquiry labs, students do not engage in any stages of inquiry, hence there is an X in each stage of phase one. Instead, through a series of prompting questions, students are introduced to the software they use to collect data for the remainder of the lab. This first phase is used as an opportunity for students to become familiar with how data is collected/analyzed using the software for that particular inquiry lab. The third difference between the two instructional models is found by observing the differences in phases (sequences) two, three, four, and five. I now describe each difference.

In phase two of their modified instructional model, the lab provides the research question and uses prompts to guide students into collecting certain data. Then students are presented with a conclusion and asked whether or not that conclusion is valid given the data they previously collected. In this phase, students only explain why they believe the evidence-based conclusion is consistent with the data and evidence.

In phase three of their modified instructional model, the lab provides a different research question and an organized set of data that is designed to allow students to easily construct an evidence-based conclusion. In this phase, students only construct an evidence-based conclusion from data that is given to them pertaining to a specific research question. There is no explicit research procedure, hence there is an X for that stage.

In phase four of their modified instructional model, the lab presents students with a research question and students construct a research procedure that could answer that question. In this phase, students do not actually collect data and no evidence-based conclusion is constructed.

In phase five of the modified instructional model, a series of prompts ask students to construct a research question, to construct a research method, to collect data, and to construct an evidence-based conclusion. In this final phase, students are engaged in one full sequence of inquiry. This fifth phase is identical to the fifth sequence of their original BFS instructional model. Appendix B contains the Galaxy inquiry lab which demonstrates what each of these phases looks like in the context of an actual student activity.

In summary, the adapted BFS instructional model differs significantly from the original BFS instructional model. Importantly, in the original BFS instructional model, there were five *full* sequences of inquiry, each in one content area. In the adapted BFS instructional model, there is a single activity (the lab) composed of five phases, only one of which engages students in a full



sequence of inquiry. The other stages engage students in specific stages of inquiry, but not full sequences as in the original BFS instructional model. This seems to controvert the claim that the laboratory materials, which use the adapted BFS instructional model, use scaffolding that is *backwards-faded*. Figure 3 demonstrates that there is no systematic fading.

***BFS assessment lab structure.***

The second type of laboratory activity that is found within their curriculum materials is an assessment lab. In the assessment labs, students evaluate mock research projects to identify inconsistencies in lines of inquiry (Lyons, 2011). Each mock research project contains purposively constructed flaws. A series of prompts invite students to assess the validity of the mock research project by finding inconsistencies within one or more of the four particular stages. The format of assessment labs is shown in Figure 4.

Mock research project	Research question	Research procedure	Data and evidence	Conclusion
1	Guides inquiry	Consistent	Consistent	Inconsistent
2	Guides inquiry	Consistent	Inconsistent	Inconsistent
3	Guides inquiry	Inconsistent	Inconsistent	Inconsistent
4	X	X	X	X

*Figure 4.* Modified BFS instructional model for assessment labs. (Lyons, 2011, p. 61)

The assessment labs differ in structure from the original instructional model. In each assessment lab, students are presented with three mock research projects, each with carefully constructed flaws in one or more of the four stages of inquiry, and each with increasing complexity. Students are asked to clearly articulate the reasons they believe particular stages contain inconsistencies. In the first mock research project, only the evidence-based conclusion is inconsistent, given the research question,

research procedure, and data collected. In the second mock research project, both the data collected and the evidence-based conclusion presented are inconsistent, given the research question and research procedure. In the third and final mock research project, the research procedure, the data collected, and the evidence-based conclusion presented are all inconsistent, given the research question. Students, through a series of prompts, are asked to identify these inconsistencies. Appendix C contains the first assessment lab which demonstrates what each of these phases looks like in the context of an actual student activity.

Given the previous description of CAPER's BFS inquiry and assessment laboratory activities, I believe that their conception of inquiry best fits within the second conception (skills) explored in the literature review chapter. In other words, CAPER's laboratory materials best align with the goal of developing students' ability to engage in inquiry. In addition, CAPER's laboratory materials are not well aligned with the goal of developing students' understanding of NOSI. This can be observed by comparing the seven NOSI tenets to the way the relevant terms within those tenets are used in the laboratory materials. For example, in the assessment labs (Appendix C) the terms data and evidence are used almost interchangeably and with little regard to their important distinctions. Additionally, the BFS inquiry labs (Appendix B) also use the terms evidence and data interchangeably. Moreover, and as Lyons (2011) described, I concur that their materials could easily give the impression to users that there is a *single* scientific method and that this method is encapsulated in the structure of all BFS inquiry labs.

***Research on the impact of the BFS labs on students' understanding of NOSI.***

There has been some empirical research into the impact of CAPER's laboratory materials on students' understanding of NOSI.

Sibbersen's dissertation study (2010) examined how 15 students working individually compared to 116 students working together in small groups, increased their understanding of NOSI after an undergraduate astronomy laboratory which used *Engaging in Astronomical Inquiry* as the laboratory materials. Through administration of the VOSI and analysis of student data, she concluded that both groups generally increased their understanding of NOSI. Sibbersen did not present sample student responses which was necessary to warrant the claim that particular students' views were naïve or informed. Sibbersen also did not follow the published analysis procedures described by the VOSI developers. Instead, Sibbersen analyzed each VOSI item separately and presented tables displaying the number of naïve or informed responses, again, with no sample student responses to warrant the description as informed or naïve. According to Sibbersen, because students working individually and students working collaboratively in groups generally increased their understandings of NOSI, she argued that it would be appropriate to offer CAPER's *Engaging in Astronomical Inquiry* in an online format.

Lyons (2011) investigated the impact of CAPER's curriculum on 220 students' views of two aspects of NOSI. The two aspects examined were the multiple methods of science and the distinction between data and evidence. Lyons, like Sibbersen, did not follow the published analysis procedures described by the VOSI developers. Lyons found a statistically significant shift towards more informed views on one of the two aspects examined- the distinction between data and evidence. Lyons found no significant shift towards more informed views on the multiple methods of science, an observation he attributed to (a) the nature of their curriculum which used a "consistently phased format in each of the activities, which may have appeared similar to the linear, stepwise sequence that appears in "The Scientific Method" model of scientific inquiry" (p. 177) and (b) the fact that the curriculum does not provide learning experiences that explicitly or implicitly compare different types

of scientific investigations. Lyons (p. 178) believed these two reasons likely served to reinforce the predominately naïve views of the multiple methods of science.

In the next section, I describe the general impact of student-centered teaching strategies, of which inquiry-based is one, in the physics and astronomy community.

### **Impact of reform efforts in physics and astronomy education.**

The disciplines of physics and astronomy have been the focus of numerous subject-specific reform efforts (McDermott & Shafer, 2002; Prather et al., 2005; Slater et al., 2010). For example, McDermott and Shafer's (2002) workbook entitled "Tutorials in Introductory Physics" has been adopted by many physics professors and has been the focus of several investigations of their impact on student learning of physics concepts (Henderson et al., 2012; Pollock & Finkelstein, 2008). In this section, I first describe the rationale for examining this literature. I then review this literature and construct several themes.

#### **Rationale.**

Outside of CAPER's laboratory materials (Slater et al., 2010), the available physics and astronomy materials do not engage students in inquiry or facilitate an understanding of the nature of scientific inquiry. Rather, they utilize general student-centered learning principles and are designed to enhance students' understanding of physics and astronomy content. They are not designed to develop students' inquiry skills nor students' understanding of NOSI. For example, *Lecture Tutorials in Introductory Astronomy* (Prather et al., 2005) is a set of materials designed to help students confront their misunderstandings of astronomy concepts. They are not designed to develop students' inquiry skills nor students' understanding of NOSI. For this reason, studies in physics and astronomy education related to these types of learning environments were not included in the previous sections of this literature review chapter because those environments did not develop students' understanding

of NOSI nor did they develop students' inquiry skills. However, in this section, I seek to characterize the general barriers of sustained use and uptake of student-centered teaching strategies in physics and astronomy. In other words, why do professors adopt general student-centered teaching strategies and why do they continue/discontinue their use? Therefore, I broaden my focus to include any general student-centered teaching strategies that are designed for use in physics and astronomy courses. In doing so, I am assuming that the barriers are general barriers which are encountered by teachers regardless of the nature of the specific student-centered teaching strategy.

### **The impact of physics and astronomy educational innovations.**

There are a number of research-based instructional strategies [RBIS] that have been created by the physics and astronomy education research community (Henderson et al., 2012). These include formal curriculum materials designed to promote conceptual understanding of content (e.g., Redish, 2004; McDermott & Shafer, 2002; Slater et al., 2010; Prather et al., 2005), as well as general guides or teaching tips based on research in teaching and learning (e.g., Mazur, 1997; O'Kuma, Maloney, & Hieggelke, 1999; Heller & Heller, 1999). As some researchers have noted (Redish, 2003; Hake, 1998), these RBIS all promote high levels of active student engagement and seek to improve student understanding of content and hence are accurately described as facilitating student-centered learning environments. Understanding the barriers preventing the adoption of curriculum materials and teaching strategies the physics and astronomy education community develops may provide insight into Richard's eventual decision to continue or discontinue using CAPER's laboratory materials in future semesters.

There have been a number of studies that investigated the use of these RBIS by physics faculty nationwide (Henderson et al., 2012; Henderson & Dancy, 2009; Yerushalmi, Cohen, Heller, Heller, & Henderson, 2010; Henderson & Dancy, 2008). In astronomy education, to my knowledge,

there is only a single empirical study which investigates the uptake and use of *Lecture Tutorials in Introductory Astronomy* (Prather et al., 2005). I now review several of these studies and draw general implications from them.

Henderson et al. (2012) collected survey data from a sample of 722 physics professors across the United States to investigate their knowledge about, and use of, RBIS. More specifically, they sought to understand differences between professors' (a) knowledge of RBIS, (b) use of RBIS, (c) continued or discontinued use of RBIS, and (d) high and low use of RBIS. Their results are presented in Figure 5.

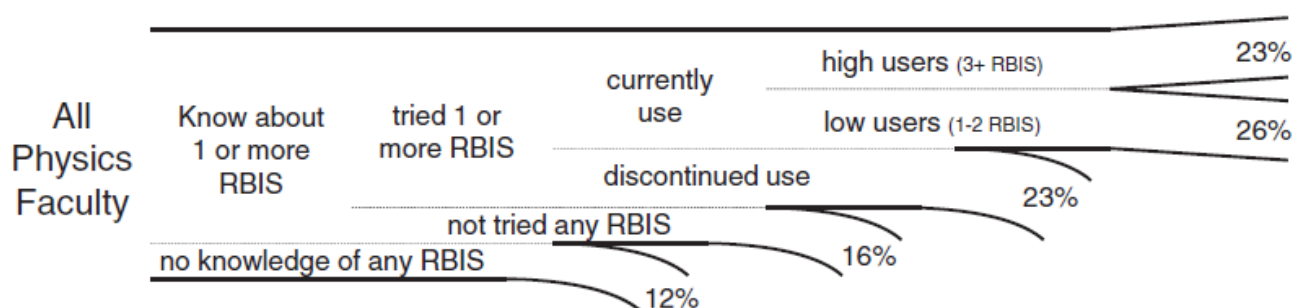


Figure 5. Where do professors opt-out of RBIS? (Henderson et al., 2012, p. 7)

Their results suggest that the majority of physics professors (88%) possess at least some knowledge related to one or more RBIS. Of those with knowledge, around 82% of them actually use them in their classrooms. Of those who used, almost 32% (23% of the initial 88% with knowledge) of them have discontinued their use. That means roughly one-half of the physics teachers surveyed still currently use RBIS. These results suggest that while current diffusion methods in the physics education community may be successful at creating knowledge about RBIS, more work is needed to help sustain teachers' use of them over time. Additionally, as helpful as these results may be, there are a few noteworthy limitations of this research and associated implications. First, an understanding of professors' knowledge about RBIS hinged completely on self-reports as measured by survey-items. Thus, we do not know if there are any important distinctions between professors' knowledge

of RBIS; that is, we do not know *what* professors' know about the RBIS, only *that* they claim to know about them. Second, we do not know *how* professors use the RBIS in their classrooms. As argued previously, no two enactments of the same curriculum materials will be exactly alike. Third, we do not know *why* some professors discontinue their use of RBIS nor do we know why some who have knowledge of RBIS never use them. Some research has been conducted which investigated barriers which prevented RBIS use by physics professors.

Henderson and Dancy (2007) investigated the self-reported barriers to the use of research-based instructional strategies of five physics professors with no formal connection to the general physics education community. This sample was purposively selected because the researchers believed these professors possessed characteristics that were representative of potential adopters of RBIS, i.e., those with little knowledge of RBIS. Through analysis of semistructured interviews, the researchers found that these teachers possessed adequate conceptions of teaching and learning, possessed knowledge of RBIS, and yet did not use them in their own classrooms. The professors described several situational barriers which prevented their adoption of RBIS. These barriers included a lack of sufficient student motivation, pressure to cover many topics, lack of sufficient time to implement RBIS, lack of departmental support, and open student resistance to RBIS. These barriers are similar to barriers discussed previously in the review of professors' perceived barriers of using inquiry-based teaching strategies (Brown et al., 2006; Cheung, 2007); this is not surprising given that inquiry-based teaching strategies are just a different type of student-centered teaching strategies. The researchers argued that if RBIS are to be adopted by more physics teachers, strategies to cope with situational barriers need to be addressed through professional development or some other venue. This, perhaps, is where Krajcik and colleagues work in educative curriculum materials may be useful (Davis &

Krajcik, 2005; Schneider & Krajcik, 2002). There have been a few studies which investigated physics TAs' experiences and challenges associated with using RBIS during lectures or recitations.

***TAs' professional development in research universities.***

Because this study takes place within the context of a research university, I examine the research on the environment TAs find themselves in during their graduate school career. Therefore, in this section, I will describe the typical guidance TAs are offered and review the few studies that existed in the physics education literature which examined TAs' uptake of student-centered teaching strategies.

In most research universities, TAs are heavily relied on to deliver much of the science instruction (Gardener & Jones, 2011). Therefore, TAs have a large role in the nature and quality of undergraduate science education in research universities. Although TAs are charged with significant amounts of undergraduate science education at research universities, they typically only receive minimal amounts of guidance or support for their instructional roles (NyQuist & Wulff, 1996). Professors recognize that their graduate students require guidance in order to become proficient at conducting research. An apprenticeship model is often implemented where TAs are initially supervised while conducting research for the first time but eventually progress to a level where the supervisors become confident in the TA abilities to conduct research independently (Feldman, Divoll, & Rogan-Klyve, 2009). Yet, no such apprenticeship model is usually available for the TA to become proficient at *teaching*. This situation arises quite naturally in an academic culture which places a premium on research over teaching, the latter being often regarded as a second-tier profession (Shannon, Twale, & Moore, 1998). This is further complicated by the fact that many science professors simply lack familiarity with undergraduate science education reforms (Baiocco & DeWaters, 1998). In the two studies I examine next, I describe the fundamental characteristics of the



TA which represents a barrier to, or factor of, the successful uptake of student-centered teaching strategies. I will argue that the findings of this research parallel the findings explored earlier.

Goertzen, Scherr, and Elby (2009) investigated how one particular physics TA's lack of buy-in to reformed teaching methods affected his teaching behaviors. TAs were charged with holding recitation sections for introductory physics using the lecture tutorials for introductory physics (McDermott & Shaffer, 2002). This particular TA did not buy-in to certain aspects of the tutorials such as valuing students' initial conceptions of concepts, using questioning strategies while responding to students, and viewing yourself, as a TA, as a learner of physics. The TA also believed students did not possess sufficient skills to complete the tutorials. The researchers argued that this lack of buy-in influenced the TA's classroom practice as he was observed to explicitly and frequently omit certain questions and did not generally ask probing questions or give initial value to students' ideas regarding basic physics concepts. Further, the researchers argued that the weekly TA meetings, which were explicitly designed to convince TAs of the benefits of the tutorials and of student-centered learning environments more generally, did not help this particular TA accommodate implementation of the tutorials. The researchers argued, at length, that the only way to modify TAs' teaching practices and hence make them able to accommodate student-centered teaching strategies is to modify their teaching and learning beliefs, and *not* by simply introducing them to and describing RBIS.

Goertzen, Scherr, and Elby (2010) investigated how one particular physics TAs' buy-in to reformed teaching methods affected his teaching behaviors in a positive way, and in a way different from the TA of their previous study above. This particular TA, unlike the TA of the previous study, attended three professional development programs specifically designed for physics TAs and additionally attended all weekly TA meetings. The TA was described as possessing positive attitudes

towards the tutorials he taught and completely buying-in to student-centered teaching strategies. He also valued and engaged with students' naïve ideas of physical concepts in a nonthreatening, friendly way. He also was observed to engage in Socratic questioning with his students when they struggled with the tutorials. The authors state that the TA's buy-in to student-centered teaching strategies is what allowed him to be a successful leader of his recitation sections. Together, the two studies above were the only two located studies in the physics and astronomy education community which investigated TAs' experiences and challenges with student-centered teaching strategies. Interestingly, the two studies parallel the results explored earlier; only when TAs come to appreciate inquiry-based teaching strategies, were they more likely to become successful inquiry TAs (Roehrig et al., 2003; Gormally et al., 2011). The two Goertzen et al. studies demonstrate explicitly how a lack of buy-in to innovative teaching methods prevents effective implementation of those methods.

This brief review of research in the physics education community suggests several implications. First, many professors appear to possess knowledge of RBIS (as measured by online surveys) and almost half reported still using at least one of them. Second, although many have knowledge of RBIS and have tried using them at least once, almost a third have discontinued use. Third, we know very little about *how* these RBIS are being used in the classroom, only that they are being used. This provides support for research which studies the use of physics and astronomy curriculum materials; this was a major focus of this study.

Additionally, physics TAs who buy-in and appreciate student-centered teaching strategies are more likely to be able to effectively support such learning environments. However, if TAs do not buy-in to innovative teaching methods, and those attitudes do not change, it is unlikely the TA will be able to effectively support such a learning environment. This situation is complicated when the TA is a graduate student in a research university. TAs in these situations typically receive very little

pedagogical support for their important roles as instructors. TAs in these settings are often the sole interface between the curriculum and the student, particularly in large-lecture settings.

### **Summary of Literature Review**

The review of the literature related to inquiry and undergraduate science education revealed very few studies which investigated how professors or TAs implemented inquiry-based learning environments. No studies surveyed clearly described the designing phase of the learning environment and without such information we have no way of knowing what contextual factors may have been at play which impacted the resulting nature of the learning environment. Many studies did not define what type of inquiry was being investigated- students' understanding of the nature of scientific inquiry or students' ability to engage in inquiry or inquiry as pedagogy. Further, a significant portion of the studies pertaining to professors/TAs and inquiry did not mention any student learning gains. Research studies related to students' experiences during inquiry-based experiences were fairly numerous. This research showed that students' personal learning beliefs are typically at odds with the expected behaviors in an inquiry-based learning environment but also showed that inquiry-based learning environments can indeed result in increased student understanding of content (Wallace et al., 2003; Duran et al., 2004). Studies gave seemingly contradictory findings related to the verbal discourses between members of a student group and between student-groups and instructors (Narayan, 2010; Krystyniak & Keikkinen, 2007).

Although the laboratory learning environment is an ideal venue for constructing inquiry-based learning environments, these goals are rarely realized, especially in college science laboratories (Buck et al., 2008). Traditional cookbook laboratory activities, where students follow step-by-step instructions and eventually arrive at pre-determined results, are by far the most common type of laboratory activity. I also described the laboratory materials adopted for use in this study's laboratory

learning environment. These materials are a combination of inquiry and assessment activities that are designed to engage students in the process of inquiry. The developers described the goal as to improve students' understanding of the nature of scientific inquiry and assessed the efficacy of their labs based on this (Lyons, 2011; Sibbernson, 2010).

I also described the nature and impact of innovative educational reforms in physics and astronomy education. I argued from this literature that (at least in physics education) professors are aware of RBIS and yet do not use them or discontinue use after an initial trial (Henderson et al., 2012). I also argued that physics professors perceived similar barriers to implementing RBIS as teachers in other disciplines (Henderson & Dancy, 2007). I argued based on these findings that more support should be offered to teachers as they adopt and adapt curriculum materials and that perhaps the work of Krajcik and colleagues on educative curriculum materials might be appropriate (Davis & Krajcik, 2005). Finally, I discussed how the physics education research was parallel to the more general findings of the science education community. Just as the broader science education community provided evidence that a lack of buy-in to inquiry-based teaching strategies represented a barrier to effective enactment of those learning environments (Gormally et al., 2011), the physics education community has similarly described the challenges that result from a TA's lack of buy-in to student-centered teaching strategies like the lecture tutorials in physics (Goertzen et al., 2009).

With this in mind, my study was designed to fill parts of the gaps that exist in this literature. My study specifically examined the design and enactment of an inquiry-based learning environment. Further, I investigated what made this learning environment an inquiry-based learning environment, whereas previous studies were often ambiguous in this regard. In light of my two theoretical frameworks and the findings from the literature review, I studied the design, enactment, and impact

of an undergraduate astronomy inquiry-based learning environment. In the next chapter, I describe the research process I used to investigate my two research questions.

### Chapter 3: The Research Process

#### Research Tradition

This research utilized a qualitative approach to data collection and analysis (Lincoln & Guba, 1985; Bogdan & Biklen, 2007). My epistemological stance is that the external world is real and exists and we can come to construct knowledge about it through qualitative and quantitative empirical methods. Additionally, I believe that we construct knowledge about reality, not construct reality itself. In this sense, I constructed my own understanding of how Richard designed the astronomy laboratory learning environment, how the TAs enacted that learning environment, and the nature of the interactions between the laboratory materials and these participants. I supported the claims made through an analysis of transcriptions of interview data as well as non-participant observations of the astronomy laboratory learning environment. I chose to adopt a qualitative framework for this study because it allowed me to deeply understand the context in which instructional decisions were being made and particular events occurred. Moreover, I do not subscribe to research programs in education which reduce the nature of the complex learning environment and the interactions among all participating members within that learning environment down to a number in order for that environment to become amenable to quantitative research methods. This does not imply, however, that I believe quantitative research cannot be used in education; to the contrary, when appropriate, it can. Instead, I'm arguing that particular questions/concerns, such as the nature and design of any complex learning environment, beg for qualitative research methods.

#### Research Questions

The two research questions that guided this study were:

- (1) *How do a beginning professor and graduate teaching assistants design and enact an undergraduate inquiry-based astronomy laboratory learning environment?*

*(2) What is the impact of that learning environment on students' understanding of the nature of scientific inquiry?*

## **Setting of the Research**

This research occurred within an undergraduate introductory astronomy course for nonscience majors at a major research university. More specifically, I collected data primarily from the laboratory sections which were supervised by TAs and weekly TA meetings where all TAs met with the course professor, Richard. In the next several sections, I describe the lecture-portion of the course, the laboratory-portion of the course, and the weekly TA meetings.

### **The lecture portion of the course.**

This course was a large-enrollment (~550 students) introductory astronomy course intended for nonscience majors. It was a four-credit course with nearly three hours of lecture contact-time per week with an additional 80 minutes of laboratory contact-time per week. The course was taught in a large lecture hall and was composed of two sections, each with several hundred students. This course satisfied the science requirement of the university's liberal arts core and was taken by students from a variety of backgrounds and disciplines. The topics of this course included: motions of the sun, the moon, and stars, the historical development of physical principles from the ancient Greeks to Newton, the nature of light and its interaction with matter, and the formation of the solar system and extra solar planets.

Each lecture was composed of a variety of student-centered learning activities. Think-pair-share questions, interactive lecturing, and lecture tutorials (Prather et al., 2005) constituted the bulk of the student-centered activities. As described previously, the lecture tutorials are a set of student-centered curriculum materials used to supplement traditional lectures. These activities are composed of a sequence of conceptually challenging questions driven by Socratic dialogue, are used to address

known student misconceptions in astronomy, have been demonstrated to be successful at addressing these misconceptions, and are modeled after similar tutorials in introductory physics (McDermott & Shaffer, 2002).

The written goals of the lectures (see in the syllabus in Appendix D) are for students to “understand the big ideas in astronomy; to develop lifelong interest in astronomy and current events surrounding astronomy.” The syllabus also stated that students would be “required to think about how we have gained such a sophisticated understanding of this part of the universe, and not simply just learn the currently accepted facts. In the process, I hope you will better appreciate the nature of scientific inquiry and its human elements.” These general goals are further developed into four specific lecture goals which are: (1) to understand the motion of the Sun, the moon, and the stars, (2) to understand how humans moved from the Earth-centered universe to our modern understanding of astronomy and our place in the universe, (3) to use the information encoded in light to understand where the Sun’s light and energy come from, and (4) to understand how the Sun and the planets of our solar system formed. I did not observe the lecture-portion of the course.

### **The laboratory portion of the course.**

The laboratory portion of the course originally was to consist of 12 labs. Each TA taught four laboratory sections each lab week. The syllabus (see Appendix D) describes a “poster conference” for lab 11. This poster conference did not take place. Additionally, during the first and last laboratory sessions, students completed a questionnaire designed to probe students’ understanding of NOSI. Therefore, these labs were not observed. Of the remaining nine labs, there were six BFS inquiry labs (labs 2, 3, 5, 6, 7, and 9), two BFS assessment labs (labs 4 and 8) and one traditional lab used from previous semesters that was selected because there were no BFS labs which covered the topic of spectra. Each laboratory period was scheduled for 80 minutes, though most times students were



observed to finish typically after the first 60 minutes. The description of the laboratory component of the course is found in the course's main syllabus, Appendix D. As can be seen upon close inspection of the syllabus, there are no listed goals for the laboratory component of the course. I conducted non-participant videorecorded observations of the laboratory learning environment of two different TAs, six times each, throughout the semester. I did not take fieldnotes during these observations. The labs observed for the first TA were composed of three inquiry labs, two assessment labs, and the traditional lab. The labs observed for the second TA were composed of four inquiry labs, one assessment lab, and the traditional labs. These particular labs were selected based only on time-availability; the interviews took place during the day when some TAs taught their labs. Each laboratory section was taught by a TA who was a physics doctoral student in the university's physics department and who was selected for this study on the basis that they were generally willing and eager to participate in it.

### **Weekly TA Meetings.**

The professor, Richard, organized all weekly TA meetings. All TA meetings were held in the laboratory room where students would meet and consisted of Richard communicating the TAs' responsibilities. During weekly TA meetings, Richard also requested that TAs complete the upcoming week's lab under his supervision. These meetings typically lasted approximately one hour in length, decreased significantly in length by the end of the semester, and the professor did the majority of the talking. I made non-participant audiorecorded observations of all TA meetings. I did not take fieldnotes during TA meetings.

## **Research Participants**

### **The professor.**

The professor of this astronomy course, Richard, was a recently tenured professor with a background in theoretical physics. His undergraduate studies were in physics and he earned a Masters in mathematics and Ph.D. in physics for his study of gravitational waves. He was also a post-doctoral scholar at a major research university and has been the recipient of numerous awards for his research in this area. His teaching experiences included an introductory astronomy course and a science and computing course. In addition to his numerous science-related awards, Richard was also a recipient of a teaching and research award, an award given to those who were committed to excellence in both research and teaching.

Richard adopted several student-centered teaching techniques that he used often during his lectures (lecture-tutorials, think-pair-share, interactive-lecturing, etc.). He became aware of these through participation in two astronomy education professional development workshops. Through these workshops, Richard began to reflect on his teaching practices and ultimately decided to adopt these student-centered techniques as a way to break apart the traditional direct-lecturing.

### **The teaching assistants.**

Two TAs agreed to participate in this study. I chose two because I desired to conduct in-depth case studies of each TA and document their interactions with the Richard, their students, and the laboratory materials. All TAs for this astronomy course were invited to participate in this study. The two TAs I studied were the only two willing to be part of my research.

### ***Peter.***

Peter was a first-year graduate student in the physics department. Although this was his first formal teaching experience, during his undergraduate years at a small, liberal arts college, Peter had

numerous informal tutoring responsibilities. During his first two years, he was charged with the setup of laboratory equipment in his college's introductory physics courses. By his third year, he assumed more of a tutoring role, helped out with introductory physics courses, led several laboratory sessions, and taught several recitation sections. Peter described himself as excited to implement these new labs and believed the weekly TA meetings were helpful and necessary, and was generally confident in his teaching abilities.

### ***Adam.***

Adam was a second year graduate student in the physics department. He had no formal teaching experiences prior to this teaching assignment and described himself as indifferent about this placement. He did not seem to mind that he was teaching, nor that he was teaching astronomy, a field outside of his expertise. He also did not exude the same excitement towards the laboratory learning environment that Peter exuded. In fact, Adam described the labs as likely being “straight forward” and “not difficult at all” and believed that the TA meetings, while helpful, were not strictly necessary because TAs could easily complete the laboratory activities during their own time and without the assistance of Richard.

## **Data collection.**

### **Sources.**

The first research question was: *How do a beginning professor and graduate teaching assistants design and enact an undergraduate inquiry-based astronomy laboratory learning environment?* To answer the research question, I collected the following data: (1) written transcriptions from semistructured interviews with Richard and the TAs, (2) written transcriptions and summaries of audio-recorded observations of each TA meeting, (3) written transcriptions and summaries of video-recorded observations of all TA introductions and interactions they had with

their students during laboratory sessions, (4) photocopies of students' written responses to their laboratory activities, and (5) other artifacts which included: the course syllabus, email exchanges between Richard, the TAs, myself, and the CAPER team, the grading scheme, and personal, written self-memos. These particular data were collected because they allowed me to investigate, in-depth, my first research question. More specifically, because I chose to structure this research within a qualitative framework, these data best allowed me to deeply understand the context in which the design and enactment of the laboratory learning environment took place. I now describe each piece of this data.

I interviewed Richard twice, once before the semester began and then again after the semester concluded. The first interview (see Appendix E for the interview protocol) focused on his background experiences, beliefs about science, teaching, and learning, perceived constraints of the laboratory learning environment, and knowledge of the new inquiry-based labs. The final interview (see Appendix F for the interview protocol) followed up on general comments from the first interview and probed his views on the teaching, learning and constraints of the new inquiry-based learning environment. I personally transcribed both interviews. This data helped me understand Richard's background, his beliefs about teaching and learning, his knowledge of the laboratory materials, his rationale for designing the laboratory learning environment the way he did, and his perceptions of the barriers to, or the success of, the laboratory learning environment.

I separately interviewed each TAs three times. The first interview (see Appendix G for the interview protocol) took place before the semester began. The second interview (see Appendix H for the interview protocol) took place midway through the semester. The final interview (see Appendix I for the interview protocol) took place after the semester concluded. These interviews focused on the TAs' background experiences, beliefs about science, teaching, and learning, perceived constraints of

the laboratory environment, and general knowledge about the new inquiry-based learning environment. I personally transcribed all interviews. This data helped me understand the background of the TA participants, their knowledge of the laboratory curriculum and their perceived constraints of that environment.

I audiorecorded all ten TA meetings throughout the semester. Meetings took place Tuesday afternoons. I transcribed all audiorecorded TA meetings. This data helped me understand the resources and pedagogical training made available to the TAs as they managed their laboratory learning environments.

I videorecorded each TA as they taught six of their laboratory sections. Each TA taught four separate laboratory sections each week. I videorecorded the first of those sections. During these observations, I videorecorded their introductions and all of their interactions with students. Each TA was videorecorded during six laboratory sessions which did not include the first or last laboratory meetings because they were used to administer a questionnaire which probed students' understanding of NOSI. I transcribed all videorecorded laboratory observations. This data helped me understand and breakdown the complex laboratory learning environment into manageable chunks.

I collected and photocopied all students' submitted and graded laboratory work for each videorecorded laboratory session. Each group member turned in an inquiry lab and an assessment lab at the end of the laboratory session. I photocopied 136 inquiry labs and 44 assessment labs from Adam. I photocopied 130 inquiry labs and 51 assessment labs from Peter. This data helped me to understand how TAs used the grading scheme provided by Richard to assess their students' written work.

Finally, I collected various other artifacts throughout the semester. This included, the grading scheme, the course syllabus, transcribed email exchanges between Richard, the TAs, myself, and the

CAPER team, as well as, personal self-memos written by me occasionally after TA meetings or at other unspecified times. This data helped me understand other facets of the learning environment not examined by the previous data described. For example, the grading scheme helped me to understand how the structure of that scheme influenced the TAs' grading practices.

The second research question was: *What is the impact of the laboratory learning environment on students' understanding of the nature of scientific inquiry?* To answer this question, I collected all willing student-participants' pre- and post- written responses to an instrument designed to probe students' understandings of NOSI called Views of Scientific Inquiry [VOSI] (Swartz et al., 2008). As I described previously, the CAPER team argued that their laboratory materials help develop students' understandings of NOSI as measured by the VOSI instrument. In fact, VOSI was the primary instrument used to collect data in both published dissertations on the impact of these laboratory materials. Therefore, I also chose to evaluate the impact of their laboratory materials on students' understandings of NOSI by using the VOSI instrument. I will ultimately comment on the appropriateness of using the VOSI questionnaire in the context of their laboratory materials in the implications chapter.

### ***The VOSI instrument.***

Schwartz et al. (2008) developed a valid and reliable, open-ended (free-response) instrument designed to assess respondent's views of NOSI. This instrument was selected to address the second research question for two reasons. First, it was the only research-validated instrument found to probe students' understanding of NOSI. Second, it was also the instrument used in the two published dissertations which analyzed the impact of their laboratory materials on students' understanding of NOSI (Lyons, 2011; Sibbernson, 2010). These two dissertations both claim that the laboratory materials are worthwhile because they led to improvements in students' understanding of NOSI as

measured by VOSI. In choosing to also use this instrument, I was able to better determine whether their findings could be replicated in a new learning environment; one in which was supervised by TAs. Recall the seven tenets of NOSI as described by Schwartz et al. (2008):

- Questions guide investigations
- Multiple methods of scientific investigations
- Multiple purposes of scientific investigations
- Justification of scientific knowledge
- Recognition and handling of anomalous data
- Sources, roles of, and distinctions between data and evidence
- Community of practice

Schwartz et al. (2008) developed items for their VOSI instrument based on these seven tenets, reviewed these items with scientists and science educators, and then conducted numerous pilot-studies to assess the validation and reliability of their instrument. Their VOSI instrument can be found in Appendix J. They describe the most desirable manner to administer the instrument as a controlled setting, where respondents provide their responses without communicating with others. Roughly 45 minutes to one full hour of time is typically needed. I administered the VOSI instrument to all participating students during their first and final official laboratory sessions. Each student worked alone, without speaking aloud. Once this data was collected, I grouped each student's pre- and post-VOSI response sheets and all student names were given pseudonyms. I ended up collecting 20 VOSI sheets from Peter's laboratory and 22 VOSI sheets from Adam's laboratory. Although each laboratory session contained approximately 28 students, some students took the pre-VOSI questionnaire and then switched or dropped the lab section; these students were excluded from analysis in this study.

## **Data Analysis**

In this section, I describe the analysis procedures I used to answer both of my research questions.

### **Data analysis for first research question.**

My first research question was: *How do a beginning professor and graduate teaching assistants design and enact an undergraduate inquiry-based astronomy laboratory learning environment?* Once all relevant data was collected, I engaged in the following six phases of analysis (Creswell, 2008, p. 243).

- Preparing and organizing the data
- Exploring and coding the database
- Describing the findings and forming themes
- Representing and reporting the findings
- Interpreting the meaning of the findings
- Validating the accuracy of the findings

Because the volume of the data collected was great, and transcription of interviews and observations took several months, this analysis did not begin until after the conclusion of the semester.

#### ***Preparing and organizing the data.***

I first organized the data. To do this, I personally transcribed all interview data, all audio-recorded data, and all video-recorded data. I also collected and electronically stored all remaining artifacts such as the course syllabus and email exchanges. This entire process took approximately 4-5 months. I then uploaded all data into the computer software NVivo (QSR International Pty Ltd. Version 9, 2010).



***Exploring and coding the database.***

Creswell (2008) described this phase as consisting of preliminary exploratory analysis, followed by coding the data. I first conducted a preliminary exploratory analysis phase where I read and reread all transcribed data, simply to get a sense of the context of the learning environment. After this initial exploration, I entered into the coding phase. During this phase, entire texts or segments of texts were labeled (coded) with descriptors that were indicative of the design and enactment of the laboratory learning environment. Creswell (2008, p. 251) described this as, “identifying text segments, placing a bracket around them, and assigning a code word or phrase that accurately describes the meaning of that text.” For example, during my interview with Richard, he described several reasons he searched for new laboratory materials. Therefore, any text which contained descriptors that were indicative of the reasons he sought to design a new laboratory learning environment, was given the code “reasons for new laboratory” in the NVivo software. A similar process ensued for other codes until all data was analyzed. Once all data was analyzed, I went back and ensured that codes had not mistakenly been mislabeled.

I then grouped codes together that were similar. Creswell calls this collapsing the codes and checking for redundancies. For example, I noticed that Richard’s modeled introductions during weekly TA meetings were extremely similar to specific parts of both TA’s introductions which were given during their actual lab sections. I therefore collapsed these individual codes (Richard’s introduction, Adam’s introduction, and Peter’s introduction) into a single code with the label “lab introduction similarities.” After this, I again went back and ensured that the collapsing of codes into more general codes was warranted on the basis that descriptors in both original codes were addressing similar things.

There were also pieces of the data that were analyzed in isolation before including them in the holistic analysis just described; that is, I analyzed some pieces of data individually and then included that data in the general analysis. This data included the videorecorded laboratory observations, the grading scheme presented to the TAs and their use of it, and group's written responses to laboratory activities. I now describe the analysis process for each.

The videorecorded laboratory observations included interactions had between TAs and students. There are many possible ways to categorize these interactions. For instance, I could have categorized them according to the lab in which they occurred. I could have categorized them according to the particular phases in which they occurred. I chose to categorize individual interactions based on (a) the type of problem encountered by the student which led to the interaction and (b) the type of response given by TAs. Each type was inferential and based on an inductive analysis of transcripts obtained from video recorded laboratory observations. The choice to categorize interactions in this way also helped untie TAs' actions from students' actions which was important given my focus and structure of my Literature review chapter; the Literature review chapter was separated by participant (professor, TA, student). This, to me, warranted the analogous separation I used to analyze the videorecorded laboratory observations. Additionally, my conception of curriculum use as *teachers' participation with the text* (Remillard, 2007) further justifies separately analyzing student questions and TA responses because I am most interested in the interactions between participants.

Once separated, I inductively analyzed students' questions and TAs' responses in the following manner. For the student-portion of interactions, I read and reread all transcripts and formed themes from codes in the same way as described previously in this section. For example, student questions occurred during particular lab phases. This became coded as "student question-phase V" as

an indication that this chunk of text gave information regarding where the question had occurred. Similarly, students typically asked TAs questions when they were unable to generate a response to a particular lab question and hence sought his/her help. This became coded as “What am I supposed to do here?” because it indicated that this chunk of text provided information regarding the motivation behind the student’s question (seeking assistance when unable to proceed). Additionally, other students were able to generate responses to lab questions and sought their TA’s approval of that response. This became coded as “Is this correct?” because it indicated a chunk of text that provided information regarding the motivation behind the question (making sure they have the correct answer).

I also separately analyzed the grading scheme provided to the TAs as well as their use of it. I analyzed this data by first describing the nature of the grading scheme and then comparing that grading scheme with student’s scores. For example, I checked for consistency between points allocated for certain lab questions by the grading scheme against student’s graded work. Finally, I also analyzed the grading scheme itself in terms of how easily it could theoretically be used by TAs to discriminate between different types of student responses. To do this, I analyzed the scheme and the guidance given by Richard to the TAs during TA meetings to determine whether different student responses could be easily identified and classified.

I also analyzed each group’s written responses to the laboratory questions. As I describe in my findings chapter, students within groups were instructed to have the same answers to phases II through V of each laboratory activity. Because of this, I could not trace written statements back to any particular individual within a group. Therefore, I analyzed a random group member’s written work and findings generated through that analysis were described at the group level, not at the individual level. I also analyzed the number of interactions each group had with their TA throughout the semester by closely analyzing the videorecorded observations.

***Describing the findings and forming themes.***

During this phase, a researcher is beginning to form answers to their research questions (Creswell, 2008). The codes are used to generate rich descriptions and broad themes. For my study, I generated descriptions of the laboratory learning environment and the weekly TA meetings and several themes from the coded data. Themes are “similar codes aggregated together to form a major idea in the database” (Creswell, 2008, p. 256). For example, one theme I constructed from the data was labeled as “the structure of laboratory sessions.” This broad theme was the result of several codes I collapsed because they all described the same phenomenon, namely, the basic structure of all laboratory sessions. Another theme that emerged through my data analysis dealt with the effect of the rules set by the professor on the structure of the laboratory sessions led by the TAs. During this phase I also searched for contrary evidence. This phase was important because unlike many qualitative studies which may be conducted with other individuals, I was working by myself and desired to maintain the strictest sense of trustworthiness. Eventually, I reached a point where my themes became saturated, that is, no new data added to my list of themes or to the detail within my themes. Once this saturation was complete, I moved on to the next phase.

***Representing and reporting the findings.***

As Creswell (2008) described, how one represents their qualitative findings is really a personal matter of taste. While I may agree with this view, I also see merit in the intentional structuring of a findings section in a way that a reader can easily see alignment between those findings and the literature review and methods that were previously addressed. I found rich descriptions of the context of my study important and so I provided this in my findings chapter. I have organized my general findings chapter temporally; that is, I begin first with the design of the laboratory learning environment, then transition into the enactment of the laboratory learning

environment, and finally I address the impact of the laboratory learning environment on students' understanding of the nature of scientific inquiry. Each of these sections contains several subsections which are typically the themes I generated through my data analysis.

***Interpreting the meaning of the findings.***

During the interpretation phase, the researcher “steps back and forms some larger meaning about the phenomenon based on personal views, comparison with past studies, or both” (Creswell, 2008, p. 265). Lincoln and Guba (1985) describe this as addressing the “lessons learned” from the entire study. In my dissertation, this interpretation phase resulted in my implications chapter. The format and structure of that chapter was dictated solely by me, based on my interpretation of the phenomenon as well as other pressing issues I felt the need to discuss (such as the role of NOSI in science education research). In this chapter, I also situated my findings in the literature review described previously.

***Validating the accuracy of the findings.***

To validate the accuracy of these findings, I engaged in several researcher-bias prevention methods. Researcher bias is a process where the researcher performing the research influences the results in order to portray a certain outcome. All human beings share biases. We are prejudiced against certain things and naturally drawn towards others. To avoid any intentional researcher bias, I attempted to document explicitly through journaling how I felt about the laboratory learning environment, the professor and TA's actions or utterances, and my general attitude towards the project. By making my biases explicit, I hoped to minimize the impact of these biases on the outcome of my study. By this, I mean that I actively sought out disconfirming evidence for the codes and themes I developed. I also attempted to triangulate my data. In data triangulation, a researcher corroborates evidence from different sources. For example, I made the claim that the rules imposed

on the TAs largely governed the nature of the laboratory learning environment. To support this claim, I drew from several data sources and these data sources were quoted at length. I also attempted to ensure the accuracy of my findings by checking for logical consistencies. One potential and serious problem with all qualitative research is researcher bias.

### **Data analysis for second research question.**

My second research question was: *What is the impact of the laboratory learning environment on students' understanding of the nature of scientific inquiry?* In general, data analysis for this section included both inductive and deductive components. First, I collected all students' written responses to the VOSI forms at the beginning and end of the semester. I collected a total of 22 pre- and post-VOSI sheets from Adam's lab. I collected a total of 20 pre- and post- VOSI sheets from Peter's lab. I then grouped together students' pre- and post-VOSI forms. Once this was accomplished, all students' names were given pseudonyms. The data analysis followed the procedures given by the VOSI developers.

Lederman et al. (2002) and Schwartz et al. (2008) stated that because there is not a one-to-one correlation between VOSI items and targeted NOSI aspects, a profile for each student needs to be holistically generated. To put it differently, there are seven targeted NOSI aspects but there are more questions than this on the VOSI instrument which probes respondent's views of NOSI. Each question offers a potential to gain insight into how the respondent perceives a particular NOSI aspect. In addition, because of this lack of one-to-one correlation, a check for deep versus superficial understanding of a particular NOSI aspect is possible by comparing the consistency, or lack thereof, in responses across VOSI items. Schwartz et al. (2008) give the following advice for analysis of VOSI:

Targeted NOSI aspects should serve to guide initial coding. Responses are reviewed and coded with descriptors related to each targeted NOSI aspect...Emergent codes are also sought, according to the methods of Bogdan and Biklen (1992). After initial analysis, the responses are reviewed several more times for further reduction, clarification and consistency.

(p. 8)

I analyzed the VOSI in this way which is similar in style to the analysis used for the first research question. I first transcribed and then randomized all response sheets so that I was blind to whether any given VOSI sheet was a pre or post-test. I then read and reread each response sheet, in a random order, to gain a cursory understanding of how students' generally conceptualized NOSI. Next, I coded each response transcript, being sure to use the initial seven NOSI aspects as the initial codes. For example, one particular student's VOSI sheet contained the phrase, "I think that data is the evidence that you collect for an experiment and is usually numbers." This phrase was coded as *data/evidence* because it provided insight into this student's view of the nature of, and relationship between, data and evidence aspect of the nature of scientific inquiry. In another example, a different student wrote, "Scientists should follow the scientific method because it is the valid way to do science." This phrase was coded as *scientific method* because it provided insight into this student's view of the multiple methods of science aspect of the nature of scientific inquiry.

Once this was done, I further differentiated the codes within one particular aspect of NOSI. For example, within the data/evidence NOSI aspect, some students believed that data and evidence were different words for the same thing, while other students believed that they were different concepts. Further, some students believed that all data/evidence are numbers, while others believed that data/evidence can be more than numbers. These types of responses were coded differently within any particular NOSI aspect. For example, statements such as "data is the same as evidence" were

coded as *data = evidence*. Once each differentiation within a particular aspect was created, I moved on to the final phase of analysis which involved comparing the differentiated codes to typical naïve and informed statements, as I discussed in the previous literature review chapter.

Using this method, each student's response sheet was labeled as "mainly naïve" or "mainly informed". These labels were constructed by me, through the data, and emerged as a result of my analysis. That is, through my analysis, it was apparent that there were only two general types of profiles that emerged from this analysis—mainly naïve or mainly informed, as measured by VOSI. Mainly naïve indicated that most of the respondent's written comments were indicative of a naïve response, although occasionally a response was labeled as informed. Mainly informed indicated that most of the respondent's written comments were indicative of an informed view, though occasionally a response was labeled as naïve. This categorization implies, as I found, that there were no "50%-naïve / 50%-informed" profiles. All profiles, both pre- and post- semester, were either mainly naïve or mainly informed. I show examples of these in the Findings chapter. After labeling each profile as mainly naïve or mainly informed, I examined individual pre- to post- gains. By this, I mean I determined whether students who possessed mainly naïve views of NOSI at the beginning of the semester developed more informed views at the end of the semester.



## Chapter 4- Findings

In this chapter, I describe the main findings of this research in three sections which are arranged temporally. Each section focuses on an aspect of the curriculum: the design, the enactment, and the impact of the laboratory learning environment on students' understanding of NOSI. In the final section, I answer the two research questions which guided this study. Before moving into the details, I will now briefly summarize the general findings of this research.

In the design phase, Richard (a) was unhappy with the status-quo nature of the laboratory learning environment, (b) learned of the new laboratory materials and had an initial favorable reaction to them, (c) adopted the new laboratory materials and their goals, (d) created a structure for the weekly TA meetings, and (e) led the first TA meeting where he set TA's expectations.

In the enactment phase, TAs (a) gave introductions which shared similarities and differences to those modeled by Richard during TA meetings, (b) interacted with their students by responding to their questions, which occurred most often during particular lab phases, (c) and used a grading scheme, provided by Richard, to assess their students' written responses to the laboratory materials. Additionally, during the enactment phase, I found that (d) most groups were able to complete any given laboratory activity without their TA's help.

In the impact phase, I found that (a) the impact of the laboratory learning environment on students' understanding of the nature of scientific inquiry was negligible, as measured by VOSI. Students did not develop informed views of NOSI after this laboratory learning environment, as measured by VOSI. In addition, after the conclusion of the semester, I found that (b) TAs believed they were successful TAs and that the laboratory learning environment had been a success, and (c) the professor believed that the laboratory learning environment was unsuccessful based on students'

negative end-of-semester course evaluations. In the following sections, I provide evidence for each of the above claims. I first begin with the design of the laboratory learning environment.

### **Designing the new laboratory learning environment**

Richard was responsible for the design of the laboratory learning environment. Richard had regular contact with the CAPER team through email exchanges and videoconferences. Richard began designing the laboratory learning environment in the summer months of 2011. The design concluded with the first TA meeting at the end of August, 2011. In the following sub-sections, I provide evidence that Richard (a) was unhappy with the status quo nature of the previous laboratory learning environments, (b) learned of the new laboratory curriculum materials and had a favorable initial-reaction to them, (c) adopted the new laboratory materials and their learning goals, (d) created a structure for the weekly TA meetings, and (e) led the first TA meeting where he set expectations for the TAs. Together, these constituted the design of the laboratory learning environment. Data used to analyze this design came from several sources, including email exchanges between Richard, myself, and the CAPER team, transcriptions of Richard's first interview, transcriptions of the first audio-recorded TA meeting, and personal memos I wrote.

#### **Unhappy with status quo.**

Richard explained that personal desperation was the main motivator for him seeking a new laboratory curriculum. During previous experiences teaching the introductory astronomy course, Richard described the laboratory component as unsuccessful based on students' dissatisfaction with the activities. During this study, Richard was teaching this introductory astronomy course for the fourth time. Previously, he had attempted to create a new laboratory learning environment with each iteration of the course.

The first time I taught the course with [a co-instructor] and we didn't mess with the labs at all.

The second time, I taught the course myself and decided to have students do a few lecture tutorials at the beginning of each laboratory session, followed by an actual laboratory activity.

(Pre-interview)

The lecture tutorials Richard referred to are a set of student-centered classroom instructional materials designed for large-enrollment introductory astronomy survey courses for non-science majors (Prather et al., 2005). These tutorials are used to augment large-lecture astronomy courses which are found in many universities and colleges. Empirical tests of the tutorials revealed that students achieved statistically significant learning gains beyond those attained after lecture alone (Prather et al., 2005).

Richard described that during his second experience teaching this course two years ago, he did not wish to construct new sets of laboratory exercises and instead decided to introduce the lecture-tutorials during the laboratory meetings. He reasoned that since the lecture tutorials were empirically investigated and were useful for students during lectures, they could also be useful in the laboratory. However, Richard stated that divorcing the lecture tutorials from the lecture and placing them in the laboratory setting rendered them ineffective.

And you're meant to do the lecture tutorials in class. I mean, you're meant to lecture in class, then give a lecture tutorial and then [the students] come back to the lecture environment and you debrief. I just think, for the students, divorcing the lecture tutorials from the lecture made them less effective and having this transition between lecture tutorials and then the traditional cookbook lab exercises didn't work. (Pre-interview)

Richard believed the awkward transition between student-centered lecture tutorials and the traditional, cookbook activities rendered the lecture tutorials ineffective.

During his third year teaching the course, Richard tried to revamp the activities himself but felt as though they were still cookbook in nature and believed his students did not find them enjoyable. Finally, after three disappointing runs of using and creating laboratory learning environments, Richard found a new set of astronomy laboratory activities that seemed different, and in his mind, better than their traditional cookbook counterparts.

### **Finding the new laboratory materials.**

During the summer of 2011, Richard happened upon the *Engaging in Astronomical Inquiry* laboratory materials (Slater et al., 2010), a unique set of astronomy laboratory activities designed by the CAPER team. Richard recalled his initial reaction upon discovering the *Engaging in Astronomical Inquiry* text.

It's the only thing out there I could find that wasn't cookbook and I didn't want to redesign all the labs myself. I decided to take the plunge myself and adopt them on my own. I don't know if it's going to work, but it's certainly better than everything I have. I have a gut reaction that these things just look better. This is something that is new. It's different. It looks like a better way of doing it [the labs]. (Pre-interview)

Richard believed this new laboratory curriculum looked promising compared to the activities his students traditionally completed as part of their astronomy laboratory experience. Richard described that the laboratory materials were designed to develop students' understanding of scientific inquiry within in the context of astronomy. This resonated with his belief that the lecture could be the environment where students learn astronomy content while the laboratory could be the environment where students learn about the process of science.

I wanted to give students something that would give them a bit more nature of science, nature of scientific inquiry training, umm, because I don't worry about the content knowledge so

much in the labs because the lectures are getting across the content knowledge of the syllabus pretty well. What would be nice is if they did something in the labs where they could use the content they learned in the lectures and hence reinforce it, but also get experience with scientific inquiry. (Pre-interview)

Richard described lectures as the environment where students learned astronomy content that could then be useful in the inquiry-based laboratory learning environment. Richard further described the differences between the new CAPER materials and the laboratory materials used during previous iterations of the course. Richard considered the previous laboratory experiences in his class as traditional and cookbook. He defined the structure of traditional labs in the following way.

[Traditional] labs are when you basically go in, you give the students something, they have a discussion about why they are going to do the thing that they are going to do, umm...there is an instruction, and then there's a space, and then they answer the question, and then move on to the next instruction, the next question. They're very structured. (Pre-interview)

Richard compared the traditional structure of labs with his vision for a better laboratory learning environment.

I also wanted to do something that would get the students some kind of nature of scientific inquiry. Something that would tell them about the process of doing science and that astronomy wasn't simply like 'Here's four pages of paper with a bunch of instructions on, you know, and fill-in-the-blanks. That's not the way science is done. So filling in the blanks is not the way science is done. (Pre-interview)

Richard described the traditional laboratory structure as a series of fill-in-the-blanks to be answered by students. Richard then contrasted this traditional structure with the structure of the new laboratory materials by describing the BFS framework.

The idea is that you have the backwards-faded scaffolding approach where you have four pieces of the lab. You have a question that you're trying to address, you have a method, you have data. And then you have the interpretation of the data to form a conclusion. (Pre-interview)

According to Richard, each activity consisted of four stages beginning with the construction of a question, followed by the developing of a method of address the question, then collecting and analyzing the data, and finally interpreting the data and forming a conclusion. Richard then continued by describing the role of the scaffolding plays.

So you [the lab] walk the students through the entire procedure the first time and then you take away the interpretation during the second go at it. So you [the lab] give them the question, you [the lab] give them the method, you [the lab] give them the data, and then ask them to interpret it. (Pre-interview)

Richard continued by explaining that in the next iteration of the cycle an additional piece of the scaffolding is taken away:

Then you [the lab] take away the data. You say to them, here's the question, here's the method, what data would you obtain if you did this? (Pre-interview)

Richard then summarized the entire structure as a process of removing pieces of the scaffolding until the students reach the final iteration where they are to engage in all four stages of the process on their own.

So it's a scaffolded approach because you give them the structure and it's faded because you remove pieces from the end, working back to the beginning. And so the idea is that by the end of class the students come away with the ability to frame a question, to design a method, to,

you know, interpret data. They're not simply working through a list of problems. (Pre-interview)

According to Richard, each lab consists of students being initially led through all four stages of inquiry. Then students subsequently engage in the entire inquiry process again, this time without being provided with an interpretation of the data. Several more iterations then follow until students arrive at the final phase where they are to develop their own research question to pursue through the inquiry process. Richard's description of the BFS labs is consistent with the *original BFS instructional model* which was intended for *lectures* (Slater et al., 2008). However, as I described in the literature review chapter, this original model was modified for the laboratory environment. Therefore, strictly speaking, Richard's description is not quite correct. I also was not aware of this until the Lyons (2011) study was published. The publication occurred after the start of this study.

### **Adopting the materials and their learning goals.**

Richard's motivation to adopt the laboratory materials was strengthened through communication with the curriculum designers.

They [the curriculum designers] encouraged me to implement these. [One of the designers] talked to me about these things very carefully. And a few of the designers were the same designers of the lecture tutorials, so I have some faith that these are going to actually be effective. (Pre-interview)

Richard continued by describing how he became even more excited as the curriculum designers shared with him their own experiences implementing their labs.

Everyone I've spoken to, which is not a huge group of people because they haven't been widely adopted, have all said that the students can do these labs. They struggle at first, in the first couple of weeks of the semester because it's not a mode of thinking they're used to. And

that then they just get it. Then they do the labs and they enjoy them. Again, this is a kind of research question for me. Some of the concepts seem somewhat ill-defined and I'm curious what happens when we actually implement them in practice. (Pre-interview)

Richard's statement towards the end that "[s]ome of the concepts seem somewhat ill-defined," is in reference to the goals of the new laboratory materials which, for Richard, were not well-defined. In fact, Richard was open about the current goals for his laboratory learning environment.

So the learning goals for the labs are, umm, not as well-defined, I guess. That is probably a reasonable statement about them. I mean, I would like to implement these labs and I would like students to come up with a better understanding of the nature of scientific inquiry. Part of the problem with these labs is: what is the actual learning goal? I've been struggling myself with this. I asked [the curriculum designers] this question and I've never gotten a clear answer as to what the goal of these labs are. (Pre-interview)

This emerging critique Richard made of the laboratory materials indicated that he was unsure of the learning goals of the laboratory materials. The CAPER team only told Richard, through video conferences, that their laboratory materials helped to develop students' understanding of NOSI. Richard, not having a concrete set of prior laboratory learning goals, adopted the laboratory materials of CAPER without being fully aware of their learning goals. Further, whether or not those laboratory learning goals fit into the existing structure of the course was not discussed.

After Richard committed to adopt CAPER's laboratory materials, he maintained a cautiously optimistic attitude towards the potential success of the enactment. He was optimistic because his initial reaction told him these activities were promising and appeared to be a more accurate portrayal of science than the type of cookbook activities his students traditionally completed during labs. Yet,



he was also cautious as he acknowledged he was not in a position to comment on their efficacy one way or another. In fact, Richard described the adoption as a leap of faith.

The labs, I'm a bit nervous about. There's a little bit of a leap of faith here doing these BFS labs. And it's a leap of faith pushed by desperation that I want to do something better and all I can see myself doing is redesigning more cookbook labs and having some better cookbook labs, but that's not something I want to get into. So I'm kind of taking a bit of a leap of faith here. (Pre-interview)

Moreover, as will be detailed next, Richard believed his implementation of CAPER's laboratory materials faced challenges not experienced by the designers. In contrast to the designers, who were also the primary instructors of their labs, Richard's labs were taught by physics graduate students. Richard believed the TAs represented a barrier towards the effectiveness of CAPER's laboratory materials and hence this provided an impetus to design weekly TA meetings in a way that could maximize the potential success of the laboratory learning environment.

### **Structure of weekly TA meetings.**

After Richard committed to adopt the new laboratory materials, he began to develop his ideas of the structure of the weekly TA meetings. First, I discuss why Richard believed these meetings were essential and then I describe how Richard designed them.

### ***Necessity of TA meetings.***

Richard considered weekly TA meetings a priority because the laboratory learning environment was going to be supervised by TAs. Richard did not subscribe to the notion that the laboratory materials could be teacher-proof. In other words, just because CAPER found success with their labs, Richard did not assume his TAs would also find success. He explained his rationale by describing how the lecture-tutorials were not teacher-proof.

I don't believe [the statement] that these labs are teacher-proof. I think that that contradicts a large body of educational research. The lecture tutorials were designed to be teacher-proof. But they aren't teacher-proof. You need training to do them. But they are teacher-robust. So the question is how teacher-robust are the [new] labs with the TA who has a strong accent, has trouble speaking English, is shy, or who doesn't have the appropriate pedagogical content knowledge? (Pre-interview)

Experience convinced Richard that teachers needed training to effectively use lecture-tutorials. He assumed the same would also be true of the laboratory materials he adopted and therefore his teaching assistants would also need some form of training. The weekly TA meetings became the context for that training.

Richard also explained why TAs required training by describing their likely attitude towards their teaching assignment.

I think that the question of whether the TAs value [teaching] is an interesting one, because, even conceptually, do the TAs see TAing as something they have to do for twenty hours a week? I think it's a function of the individual TA. I try and instill in my TAs a sense that teaching is important both for the intrinsic sense and for their education, right? I mean, if they want to go tenure-track faculty, then the ability to teach is a useful ability. Whether or not the TAs take that message to heart, I think, is a function of the TA. (Pre-interview)

Richard believed that the question of whether the TAs were passionate enough about their teaching to pick up his messages was a strong function of the *individual* TA. TAs, presumably, either value teaching or they do not. He further described the wide range of TA abilities in terms of their ability to respond to student questions.

There's a huge range of abilities for the TAs. There are very engaging TAs who know how to teach, ask questions, Socratic dialogue, all this type of stuff. Then there are TAs that just tell the answers. I think the [new] labs will be more robust against TAs that just tell answers, because the labs aren't just looking for an answer, they're being asked for a research question. So TAs can't just say  $g=9.8$  meters per second squared, so write 9.8 here and carry on. (Pre-interview)

Richard believed that TAs would not be able to give simple yes/no or numerical answers to the new laboratory materials because these materials were not asking for those types of responses.

Richard also described what he hoped TAs would be observed doing while teaching their laboratory sections.

Ideally the TAs will go around and look at what the students are doing and question and flag the students if they were doing something that the TA saw was incorrect and get them back on the right path. They should do this before [the students] hand in their labs at the end, but that will probably be done to varying extents. Again, I think it's going to be a strong function of the TA. (Pre-interview)

Richard believed TAs should be actively searching for student groups that are deviating from what he perceived to be the ideal track. However, he also voiced fears of what TAs might actually resort to while in the laboratory.

What I'm frightened a little bit about is that I will do the labs for the TAs [during the TA meetings], you know the TAs will come up with a research question and then when they do their labs and when their students do the labs, I'll get twenty identical research questions because the TA says: Oh, the research question you're looking for is blah, blah, blah. (Pre-interview)

Clearly, Richard was concerned that the students would simply receive their research question ideas from their TAs rather than from an exchange of ideas among group members.

To summarize, Richard believed TAs varied in terms of their innate passion for their teaching assignment and their natural ability to respond to students' questions. Additionally, Richard believed that TAs should be interjecting when a group was not proceeding in the ideal direction but worried that TAs would end up just giving students direct answers to their questions. Richard attempted to structure the weekly TA meetings in a way that addressed these concerns.

*Structure of TA meetings.*

Richard decided on the general format of the TA meetings quickly. He would be the leader of all TA meetings and would communicate his expectations of the TAs. Richard described the basic structure of each TA meeting. First, he would model an acceptable introduction to communicate his expectations of their actual lab introductions. Second, he would have the TAs work through the upcoming laboratory activity under his supervision so he knew the TAs had done the lab before supervising their students.

Richard believed introducing each laboratory activity was a necessary component of the laboratory-learning environment in order to help students transition into class.

I will give a bit of an introduction, I mean, it helps the students to have some sort, rather than coming in and just start working, to have some transition between, this is the start of the lab. So I'll say, you know, today we'll be looking at an exercise that looks at stars, or something like this. And then I'll have the TAs do the lab. (Pre-interview)

Richard also believed it would be useful for the TAs to work through the laboratory activities under his supervision.

What I will probably do is, I will actually have the students do, I will meet with the TAs for, I think, probably an hour and a half or two hours on Fridays. And then I will have the TAs do the backwards-faded scaffolding labs that they're going to be doing with students the following week. (Pre-interview)

Richard also stated he would interact with the TAs during TA meetings in a manner consistent with the way he expected them to interact with their students. In doing so, he hoped his TAs would be able to adopt his approach of interacting with student's ideas. The structure of Richard's TA meetings was remarkably similar to the general structure of two professional development workshops he previously attended. During these workshops, which I also attended, participants learned how to implement lecture-tutorials and think-pair-share questions (Prather & Brissenden, 2008). During this workshop, participants assumed the role of "B- astronomy students" while the workshop leaders assumed the role of instructor. Instructors communicated acceptable implementation and interaction practices through actual, situated, encounters with participants (Prather & Brissenden, 2008).

In a personal meeting with me one day prior to the first TA meeting, and captured by my personal written memo, Richard elaborated on his plans for the overarching structure of the first TA meeting. This included describing the structure of the laboratory activities, describing his expectations of the TAs, and describing the grading scheme they would use to assess their students' work.

### **First TA meeting.**

The first TA meeting took place during the first week of lecture, one week before labs met. This meeting lasted one hour and eleven minutes and Richard spoke the vast majority of the time. Richard began by welcoming the TAs and performing a roll call. Richard then transitioned and described the new laboratory curriculum as something his TAs had "likely never encountered

before.” He proceeded to dispense the Slater et al. (2008) paper which described the basics of CAPER’s backwards-faded scaffolding framework. Richard then explained the basic structure of the laboratory activities and defined the term “scaffolding.”

A scaffolding, when you're teaching students, is the structure and support for what the students need to get through the problem. And so the four elements of the scaffolding are explained in this little table. So there's a research question, a research procedure, data analysis and evidence, and a conclusion. So that’s what these labs are trying to get across to them.

At this time, the TAs flipped through the article. Richard continued, citing Slater et al’s (2008) claim that the most difficult part of the entire inquiry sequence is generating a research question. Therefore, Richard remarked, students only generate their own research question during the final inquiry sequence. Again, the TAs quietly listened to Richard speak. After a few minutes, he concluded by describing the personal assurances he received from the designers, namely, that students could be successful with the laboratory materials. He also briefly described the difference between the inquiry labs and the assessment labs, a subject he stated he would explain in later TA meetings.

Richard also described his primary expectations of the TAs during the semester. I call them *primary* expectations because Richard wrote them on the white board located in the front of the room, perhaps an indication of their importance. At this time, the TAs began taking notes. The primary expectations were as follows.

- (1) You need to be here at least 5 minutes before your start time.
- (2) Start the lab on time. Do not wait for late students.
- (3) Link the lab to lecture during the introduction.
- (4) Grade the pre-labs after giving your introduction.
- (5) Collect labs at the end of each lab period.

Richard described the rationale for each primary expectation. Number three is of particular importance because Richard spent a significant amount of time discussing it and because it appeared to have a visible effect on TAs' behaviors in their laboratory sessions. This effect is explored in the enactment section of this chapter. For now, I present Richard's description of the introductions.

Richard made clear that TAs' introductions should contain specific information. He explained their job was to link the laboratory to the lecture material.

But your job is basically to link the lab to the class. So, you know, what are we going to look at? What data set will they be using? You know, why should they care? So what your job is going to be is to link the lecture to the lab. And I'll give you exactly the key points I want you to hit. And unlike last year, this should be less than 5 minutes. (TA Meeting #1, 8/25/2011).

This constituted a rule that TAs were obligated to comply with. At this time, TAs were taking notes while Richard spoke of the importance of linking the laboratory to lecture.

Richard used the remaining time to describe other expectations he had regarding their laboratory behaviors. He was clear, and repeated himself often, that as teaching assistants, "you should never be sat at the front of the classroom waiting for questions." He explained they should approach groups and ask probing questions to make sure all students are "doing OK". TAs quietly listened as Richard communicated these rules.

Richard also took the time to describe in detail his expectations of their responses to students' questions. Richard required his TAs to use questioning techniques to foster the group's critical thinking.

What you should be doing is answering the students' questions. As soon as you answer the question, butt out. And don't just give them the answer. Try and elicit some response from them. 'What do we put for this?' Well, what do you think you should put for this? What are

you thinking about here? Be a little bit, you know, don't just be the answer giver who says, oh yea, a good research question is, what time does the moon rise or whatever. So you want to encourage them to discuss it between themselves. (TA Meeting #1, 8/25/2011)

The TAs were instructed not to respond to students' questions by immediately giving them the desired response. Rather, they were to foster group discussion by asking probing questions with the expectation that the group would then be able to generate the desired response. Richard made clear that "it will help them [the students] do the lab if they have to explain it."

Richard concluded the first TA meeting by stating that by "talking to [the curriculum designers], I'm confident that these can be successfully implemented." He also included a brief description of the grading scheme he expected them to use to assess their students' written work. Although he admitted it was not yet complete, he outlined its general characteristics.

Each student's grade on any given lab would be composed of two separate grades. First, a group grade would be given to every group member based on the grading of a randomly selected group member's phases I through V. Richard reasoned groups would work together to complete phases I through V and so would be nearly identical, therefore warranting the same grade for each group member. The second grade would be an individual grading of phase VI, the summary phase of each lab. Richard stated that individual group members would need to have unique responses to the summary phase, therefore warranting individual grading. Together, a group grade and an individual grade could earn a maximum of 20 points. Allocation of points was to be determined by Richard at a later time. During this first TA meeting, the only substantive question asked by the TAs occurred when Adam asked in regards to the level of increasing difficulty of labs, "Do these roughly scale in order, I mean, that the easier ones are early and the harder ones are later?" Richard responded by describing the nature of the assessment labs.



Yea, and in fact they have to redesign one of the assessment case studies during the assessment labs. And, umm, of the three cases, the first one is slightly broken, the second is more broken, and the last one is just a complete disaster. So yea, it steps up as the semester goes on. (TA Meeting #1, 8/25/2011)

This was the only substantive question asked by any of the TAs during this first TA meeting. The TAs mostly sat passively, occasionally taking notes, but for the most part listened in silence.

Richard's description of the BFS labs makes it clear that the term "inquiry" refers to "inquiry skills" as discussed in the Literature Review chapter. That is, Richard believed the laboratory materials engage the students in the *process of scientific inquiry*. This is also the message that the TAs picked up from the first TA meeting. For instance, Peter described the laboratory materials in the following way:

The labs are asking them to step into the shoes of a researcher and say, ok, ask a relevant question. Not just a random question that comes to the top of your head. A question that actually has some significance and that you can actually get significant answers out of. (Peter, interview #1)

Peter continued, describing how the labs introduce the students to the concept of scientific research:

It seems to be trying to give the students a sense of what scientific research actually is. You know, teaching them what it really means to think of a research question, what is relevant data, what's not relevant, how to structure scientific research. (Peter, interview #1)

For Peter, the purpose of the labs was to allow students to become familiar with scientific research and part of that entailed understanding ideas like research questions and the relevance of data. Adam, too, echoed similar sentiments as he described the laboratory materials:

I think the labs are not merely to teach astronomy but to teach logical thought and logical hypothesis testing. As far as I can tell from what I've seen in the labs, it's very much like, kind of holding their hand through the [process]. Like coming up with an idea you want to test. Coming up with a method to test it. Testing it. Looking at the results. And then trying to extract useful trends or extrapolate or something like that. (Adam, interview #1)

The TAs believed that the laboratory materials afford students the opportunity to become scientists and engage in scientific inquiry. Neither TA, however, articulated exactly that the laboratory materials broke down each sequence of inquiry into four separate stages.

### **Summary of the design.**

Richard became aware of *Engaging in Astronomical Inquiry* (Slater et al., 2011) in the summer months of 2011. After experiencing an initial reaction that these labs looked promising, he contacted the CAPER team to ask more questions. Through these communications, Richard became even more committed to adopting the laboratory curriculum in the fall of 2011. However, he did express some reservation as these labs would be taught by inexperienced teaching assistants. This uncertainty notwithstanding, Richard adopted the laboratory materials wholesale.

Richard then developed the structure of his TA meetings which he considered essential because the newly adopted laboratory materials were going to be supervised by inexperienced physics doctoral students. He decided he would model an acceptable introduction and have TAs work through the labs under his supervision. In doing so, Richard would communicate his expectations of their teaching practices in their own laboratory sessions. During the first TA meeting, Richard described the basic features of the course and lab. He also articulated five primary expectations he had of the TAs. These included linking the lab to lecture, being proactive in lab, and responding appropriately to students' questions. Linking the lab to lecture was especially important as Richard

spent large parts of subsequent TA meetings communicating appropriate introductions. TAs, however, did not generally attend lectures and were generally uninformed about the particular concepts discussed in the lecture. Therefore, Richard alone was responsible for informing the TAs about which parts of the lab should be linked to particular concepts of the lecture. This may have been a simple task for Richard as he was clearly familiar with the lecture material. Thus, for him, the connection between lab and lecture likely was obvious. The TAs, in contrast, had no such anchoring and would be left to rely solely on the statements of Richard during introductions he would give during TA meetings.

Richard concluded the first TA meeting with a tentative description of the grading scheme which consisted of a group grade and an individual grade. After the first TA meeting, Richard was both excited and nervous for the labs to begin. He felt happy about his overall approach and vision for the laboratory learning environment and commented that the enactment of his vision was now in the hands of the TAs.

As mentioned previously, Richard's description of the inquiry-based laboratory materials makes it clear that the term "inquiry" is meant to refer to "inquiry skills" as discussed in the literature review chapter. That is, through these laboratory materials, students engage in the process of inquiry. This view of inquiry as scientific process was picked up by the TAs as well. Although TAs appeared to have knowledge of the general tenor of the laboratory material as putting the student in the shoes of a scientific researcher, they did not articulate the particular stages of each inquiry sequence nor did either TA mention the term scaffolding or its purpose.

### **Enacting the new laboratory-learning environment.**

The TAs were responsible for the enactment of the laboratory materials. Although the TAs were responsible for the enactment, weekly TA meetings were used as opportunities for Richard to

exert continual influence on that enactment. The enactment began with the first laboratory session during week two of the semester and concluded with the final laboratory session during week fourteen of the semester. In the following sub-sections, I present evidence that (a) TAs gave introductions which shared similarities and differences to those modeled by Richard during TA meetings, (b) TAs interacted in particular ways while responding to students' questions and students' questions occurred most often during particular lab phases, (c) TAs used a grading scheme, provided by Richard, to assess their students' written responses to the laboratory materials, and (d) most groups were able to complete any given laboratory activity without their TA's help. Data used to analyze this enactment came from several sources, including transcriptions of video-recorded observations of TAs as they supervised their laboratory sections, transcriptions of audio-recorded TA meetings, transcriptions of interviews with Richard and the TAs, and photocopied inquiry and assessment labs which students' completed.

### **TAs' introductions.**

The TAs were required to give brief introductions during their laboratory sessions. The nature of their introductions was influenced by Richard's modeled introductions which he communicated during weekly TA meetings. During the first TA meeting Richard described the purpose of these introductions.

But your job is basically to link the lab to the class. So, you know, what are we going to look at? What data set will they be using? You know, why should they care? So what you're job is going to be is to link the lecture to the lab. And I'll give you exactly the key points I want you to hit. And unlike last year, this should be less than 5 minutes. (TA Meeting #1, 8/25/2001)

During this first meeting, Richard communicated the purpose of TAs' introductions. In subsequent TA meetings, Richard modeled introductions to specific labs and highlighted important information

he expected TAs to communicate to their students. Because TAs did not generally attend lectures, this modeled introduction represented the only opportunity TAs had to learn of the content of the lecture, save general information contained in the syllabus. During Richard's introductions, TAs were observed to extensively take notes. I next describe the structure of Richard's modeled introductions for inquiry and assessment labs.

***Inquiry lab introductions.***

Richard delivered similar introductions during each TA meeting. Each time, Richard's introductions (1) explicitly linked the lab content to the lecture material, (2) described the basic structure of the lab, and (3) used interactive lecturing techniques to elicit TA responses. Below, I present Richard's introduction of the Galaxies inquiry lab as evidence of this structure and then compare it with the TAs' introductions. The Galaxies inquiry lab can be found in Appendix B and is officially titled "What's way out there? The Hubble Ultra Deep Field." The choice to present this particular lab is one of convenience and representativeness; it was relatively one of the shortest introductions given by Richard and consequently also one of the shortest given by TAs and it also demonstrated the structure of the other introductions. To help readers situate this particular lab within the broader course and to help readers understand the terminology used by the professor and the TAs during their introductions, I will briefly describe the basics of this lab as well as relevant background information.

At this point in the lecture portion of the course (see Syllabus in Appendix D), students will have learned about the Celestial Sphere Model [CSM] of the universe. The CSM of the universe, like all models, is a simplified representation of something. In this case, it is a simplified representation of the apparent nature of the universe. In this model, the Earth is at the center of the universe and all other objects (Sun, moon, planets, and stars) revolve around the Earth. Although we now know that

the CSM is not an accurate depiction of the way things appear to be, it nevertheless was used in ancient times (and can still be used today) to predict the motions of most visible celestial objects with a high degree of accuracy. During the sixth TA meeting (9/27/2011) for this lab, Richard stated that although this Galaxies lab is actually the first lab in the laboratory materials, he didn't feel it was appropriate for students to complete it until that week when students were beginning to transition away from the CSM to the heliocentric (sun-centered) model of the universe.

The Galaxy lab has students examine images captured from the Hubble Space Telescope. In the early 2000s, astronomers pointed the Hubble telescope at a small, seemingly blank patch of sky and took an extremely long-exposure picture. The resulting image, called the Ultra Hubble Deep Field, displayed thousands of galaxies. In this lab, students use the Ultra Hubble Deep Field image to determine general patterns of galaxy color, size, shape, and distance. (see Galaxy lab in Appendix B). During phases II through IV, students are presented with research questions such as "What is the general distribution of galaxy colors" and "What is the most common type [shape] of nearby galaxies?" During the fifth phase, students are asked to generate their own research question which is different from the previous ones and, of course, is constrained by the type of data the Ultra Hubble Deep Field contains. I encourage the reader to survey the Galaxy lab (see Appendix B) before reading on.

During the sixth TA meeting, Richard modeled an introduction for the Galaxies lab. I present his introduction in its entirety in order to easily compare it to the TAs' introductions of this same lab.

The spiel you want to give them is, basically say, OK, so in the previous few weeks we've been looking at the celestial sphere model. And you can ask them, you know, is the celestial sphere model real? Yes or no? And they should say, no, the celestial sphere model is not real,

it's just a model. Then say, OK, now the point of this lab is to take a look at what's out there in the deep universe. And we'll be taking a look at something called the Hubble Deep Field. How many of you have heard of the Hubble Space Telescope? They should all raise their hands, right? Well, some people got some observing time on the Hubble Space Telescope and they pointed it at a big empty region of space. They pointed it away from all the known stuff, the, you know, any stars or planets or galaxies that we know about and pointed it at what looked like an empty region of space and they took a really long exposure photograph of that empty space. And what they saw was thousands and thousands and thousands of galaxies. So you looked, in phase one, you looked at the Hubble Deep Field image, and the things that you're seeing in this image are galaxies. Does a galaxy contain a single star, yes or no? [TAs say no] No. Right. Galaxies contain billions of stars. So our Milky Way galaxy contains billions of stars. And there are different types of galaxies. So what you'll be doing in this project is you'll be taking a look at the different types of galaxies that you can see that are out there in the Deep Field. And you'll be exploring the universe and learning about our place in the universe with the correct sun-centered model of the solar system. And you'll gain an understanding of the nature of stars and galaxies in the universe. And that's what we'll start doing in this whole section of the class. So this section of the class goes up until the next midterm and then we'll look at light and spectra and how we use telescopes. But in this lab we'll first take a look and see what you can see when you look out there into space in a region that people thought that there was nothing much there. When you look deep into space you see all these galaxies. So that's what you're going to be exploring today. This is a lab like ones you've previously done. You should all have the prelab which familiarizes you with the software. If you have problems, the links are on blackboard here, one link is broken. The link

from blackboard will take you to that website. And then you're doing phases 2, 3, 4, 5 together in the group and then phase 6 is the individual work. Any questions? OK. (Sixth TA Meeting, 9/27/2011)

Richard (a) explicitly linked the lab content to the lecture content both at the beginning and end of his introduction, (b) detailed the tool, the Hubble Deep Field, they'd be using, and (c) engaged the TAs through "interactive lecturing," a term Richard described as eliciting responses from students and thereby forcing them to be active. I next describe the TA's introductions and compare them to Richard's. I begin with Peter.

Ok, we're doing lab one in the book. It's called the Hubble Deep Field. And I'm not sure if you guys are familiar with it but basically what we decided to do was point Hubble at a very, very blank area of space. What we thought was very blank. So, very few stars in the area and they say, ok there's a blank patch of sky, let's stare at it for a while. And they took a very, very, very long exposure photograph. And when it was taken in, well you guys saw the picture underneath the prelab, thousands and thousands and thousands of galaxies. Which, you know, provides all sorts of insight as to the age of the universe, and things like that, how galaxies develop, you know, it just gives us a wealth of information. So today, basically what you're going to be doing, is very similar to the prelab. You're going to be looking at different types of galaxy classifications, the distribution of galaxies, different things about them, using the Hubble Deep Field because it's just, a galaxy zoo. It's just ridiculous. And today we're back to the regular layout of the lab again. You know, it's phase one through six, umm, phase five being a research question. Phase six being individual. You know, back to the grading scheme we'll use the rest of the year. The thing with the questions in this lab is, they really are simple questions in general. Like they ask you, like, the sizes of galaxies being large or small,



umm, the different colors of the galaxies. Umm, what I'll say I guess, is that when you're approaching these problems, decide how you're going to differentiate between things. You know, what you consider large, what you consider small. And, keep it simple. I mean, you don't need to make a list of, like, medium sized, a little-bit-bigger than medium, huge galaxies, tiny ones, just, you know, think of a scale and, you know, don't do any more work than you have to. OK, I think that's really all I have to say. Did anyone have any problems with the prelab? (Lab observation, 9/28/2011)

This introduction by Peter was typical of his other introductions for inquiry labs. Peter (a) described the content of the lab, (b) described the tool students would use in the lab, and (c) described parts of the lab where he believed students would experience problems. These three items were always found during Peter's inquiry lab introductions: content, tool, and potential problems.

In his introductions, Peter attempted to introduce the lab in the same way as Richard. He used similar phrases, such as "point Hubble at a very, very blank area of space" and "took a very, very, very long exposure photograph" and "we're back to the regular layout of lab." However, Peter did not explicitly connect the lab content to the lecture material. In fact, Peter never explicitly explained how the lab was connected to material from the lecture in any of his inquiry lab introductions throughout the semester. Instead, he only described the content of the lab. The connection of that lab content to the lecture was apparently left for students to make themselves. To connect the lab content to the lecture material, Peter would have had to make explicit what students were discussing in lecture and then relate that to the content of the lab. Yet, he never did this, which is not too surprising given that lecture content was not a focal point of TA meetings and the fact that Peter did not attend lectures.

Adam's introduction to the Galaxies lab was superficially similar in structure to Peter's, yet noticeable differences can be seen.

Umm, hopefully, everybody figured out the, umm, prelab. So yea, umm, hopefully this is kind of straightforward for you guys. We're looking at images from the famous Hubble Space Telescope. Umm, one important thing which hopefully you already realize from the college teacher's email is that some of the links in the lab don't work. Hopefully through blackboard or the email you've found the right links. They're also written on the board. So, yea, get going and if you have any questions, umm, oh yea, an important question I had during the lab is the distinction between spiral galaxies and circular, round, elliptical galaxies. Spirals, if you see arms on it like Milky Way sort of thing, it's a spiral galaxy. If you don't see any sign of arms, it's round or elliptical. Yea, so we're back to the original [phase] two through [phase] five group work, [phase] six individual. So yea, get going. (Lab observation, 10/3/2011)

Adam's introduction, upon careful analysis in this particular case, contained three basic parts- content, tool, and potential problems. The content was galaxies, the tool was the Hubble Deep Field, and the potential problems were where students might experience difficulty categorizing certain galaxies. Like Peter, these three parts were evident during each of Adam's inquiry lab introductions. However, Adam's focus within each of these three parts differed significantly from Peter's. Whereas Peter focused primarily on replicating many of the same words and phrases as Richard, Adam focused more attention on where students might experience problems with particular wording or with the software.

That TAs included potential student problems in their introductions, an idea never communicated by Richard during any of the TA meetings, perhaps indicating that the TAs believed it was not a prudent use of students' time to struggle with the labs. Indeed, Adam stated this explicitly

during his final interview when he stated, “It seems like a waste of their time, to be spending time writing up something that’s incorrect, you know?” Further, both TAs conveyed the message that the labs were “simple” or “straightforward.” This view was also repeated during the introductions of other labs. For example, during Peter’s introduction to the Constellations lab, he stated, “...and this lab is not really that complex.” Adam was even more blunt about the simple nature of the labs.

During all six of the labs I observed (four inquiry labs and two assessment labs), Adam was recorded stating: “not expecting any problems” or “nothing too difficult” or “should be quick and painless” or “no stumbling blocks” or “should be a really easy lab” or “don’t think you’ll have any problems.” These quotes make it clear that Adam generally believed that his students would not experience problems with the concepts in the lab, though given his introductions he was concerned that his students might experience problems with particular wordings or with the software. These small potential problems aside, Adam believed the labs would be straight-forward for students. This seems to stand in direct contrast to the general tenor of scientific inquiry. Authentic scientific inquiry is *not* a straightforward, simple endeavor, as I described in the literature review chapter (see also, NRC, 2000; NRC, 2012).

Richard communicated the required structure of TAs’ introductions for inquiry labs and the TAs generally complied, in the sense that they presented their laboratory sections with introductions, but they differed significantly in style. Richard also required TAs to give introductions during the assessment labs.

#### ***Assessment lab introductions.***

During the TA meeting focused on the first assessment lab, Richard described the assessment labs as “the hardest lab for [students] because you’re asking them to think about other people’s work and comment on other people’s work and that’s not something they’re used to doing.” Richard

required all students to complete the first mock inquiry research report as the prelab so they could experience the difference between the inquiry and assessment labs before entering the laboratory.

Like inquiry labs, Richard had expectations about the structure of TAs' assessment lab introductions. He expected their assessment lab introductions to contain two parts. First, TAs were to explain the general difference between the assessment labs and the inquiry labs. Second, TAs were to elicit student responses to the prelab and address any misconceptions. Each represented additional rules TAs were expected to comply with. Both TAs complied fully with the first rule. Richard told them exactly what to say while describing the assessment lab and both TAs communicated that basic message. Both TAs also elicited student responses to the prelab, with varying success. Peter was able to easily elicit student responses while Adam was not. In addition, when confronted with students' apparent incorrect responses, TAs did not interact with those students in similar ways. In what follows, I provide Richard's introduction to the first assessment lab (see Appendix C) and then compare this to the TAs' introductions. As with the inquiry lab introduction presentations, I will first give the reader a brief background.

The first assessment lab (of the two) occurred during the fourth week of the semester. The assessment labs present students with three mock research reports. These three mock reports are *Monitoring the Moving Constellations*, *Observing the Sun's Position and Motion*, and *Monitoring the Zodiacal Constellations* (Appendix C). Students were instructed by Richard to complete the questions pertaining to the first mock report (*Monitoring the Moving Constellations*) as their prelab. Richard stated that TAs' introductions should be focused on going over students' responses to the first mock report. He made it clear he expected TAs to elicit student responses. In what follows, I present Richard's modeled introduction to the assessment lab in its entirety. I will occasionally breakup this lengthy passage to draw the reader's attention to pertinent information. As before, I encourage the

reader to look through the first mock research report, *Monitoring the Moving Constellations* (Appendix C) before proceeding.

Richard: Ok, question one just asked you to restate the research question. So let's think about question two. Does everybody agree that the plan presented is going to yield the necessary evidence to fully answer the listed research question? Do you think yes, maybe, or no?

TAs: Yes [All TAs say yes].

Richard: Yes, right? Somebody say no because you might get that, right? I mean, why might it be no?

Adam: Well it seems like they haven't included enough specific...

Richard: Right, so they might want to be a little bit more specific, but generally this is fine.

They might want to include more specific things, like what time is sunset, but generally it's fine.

In the first part of this exchange, Richard elicited responses from TAs. Richard's request of "somebody say no" indicated he believed it was possible a student might say no. Richard responded by acknowledging the TA's response, agreeing with it, but ultimately dismissing it. Richard concluded this exchange by telling the TA the acceptable response. In the next part of this exchange, Richard gives TAs explicit advice for correcting student's unacceptable responses.

Richard: Ok, do you think enough evidence has been collected to answer the research question? Yes or no?

TAs: Yes. [All TAs say yes]

Richard: Yes, Ok? So there's lots of evidence here that's asking, you know, different days of the year, when Orion's visible, and so they've collected a lot of data to answer the question.

Richard: Have they claimed more than the evidence supports? Yes or no?

TA1: No

TA2: Umm, no?

Richard: You might get some students to say yes here. One of the things the students have difficulty with is these evidence-based conclusions. They're not used to evidence leading to a conclusion. The thing that's wrong here is, the students have not claimed more than the evidence supports. They have evidence that supports the statement. The problem is they haven't answered the research question. So if any students have the misconception that, you know, say, well, no, let's take a look and see what, the statement is. Somebody tell what the statement is. Well, the statement is blah, blah, blah. And you can see from the table, you know, just take a look at the table. And give them time to read it right? Say, look at the table, is there evidence in the table to support that? Discuss this amongst yourselves.

Richard believed students may be unable to provide the acceptable response to this question. Richard tacitly implied that although the acceptable response is no, some students may incorrectly say yes. Richard's advice for correcting an unacceptable response like this involved asking the student to reread certain statements. In doing so, Richard assumed the student would then see the error in his/her logic and be able to provide the correct, acceptable response. In the next part of this exchange, one TA (not Adam or Peter) provided a genuine response to Richard's question. However, Richard deemed his response to be unacceptable. In this exchange with this TA, Richard implemented a teaching practice he expected his TAs to use in their labs.

Richard: OK, have assumptions impacted their results?

TAs: [All TAs, except one, say no]

Richard: [Question directed only to TA3] What assumptions do you think impacted their results?

TA3: They haven't observed, umm, the research question says [...] Oh, whoops, I was misreading the question. The question says, just after sunset. Never mind.

Richard: OK, so that's a perfectly reasonable thing a student could do, right? You realized when you said it out loud that you messed up. And that's something the students will do. When they have to vocalize some of this stuff, they'll realize they messed up.

Richard: OK so next question. Does the claim directly answer the original research question? Yes, maybe, or no?

TAs: No. [All TAs say no]

Richard: No. Why doesn't it answer the research question?

TA3: [This is the same TA as TA3 above] Mine was because, I said it isn't exhaustive enough to make the claim of visibility throughout the night.

At this time, Richard believed this to be an unacceptable response to the question. He then interacted with this TA in a manner he expected his TAs to mimic during similar situations.

Richard: OK, what is the research question? Tell me what the research question is. And, you know, I'm doing what you guys should be doing with the students. Read the research question to me.

TA 3: In which season is the constellation Orion high in the southern sky just after sunset?

Richard: OK, read the conclusion, read the evidence-based conclusion for me.

TA 3: From the evidence above, we can see that the constellation Orion appears to move from low in the eastern sky to low in the western sky from January to May.

Richard: OK, what was the research question? Read the first three words of the research question.

TA 3: During which season.

Richard: Right? Is the constellation high in the southern sky. Have they mentioned seasons in their conclusion?

TA 3: Not really.

Richard: Not really, right?

In this exchange, Richard modeled the way he expected his TAs to interact with their students. Again, Richard's approach entailed the student rereading certain pieces of information in a particular order determined by the instructor. The student would then be able to provide the acceptable response through the lead of the instructor. In his approach, the student, not the teacher, ultimately generated the acceptable response. Richard told me after this TA meeting, as captured on my personal written memo, that he noticed most of the TAs did not write anything down and worried they were "just going through the motions." He feared the TAs would not handle students' unacceptable responses in a way that "doesn't leave them feeling stupid." I now display parts of both TAs assessment lab introductions. I chose specific parts because it highlights how their approaches to student's unacceptable responses differed from Richard's approach. I begin with Peter.

Generally speaking, Peter took seriously all students' responses, acceptable or otherwise. Many students offered responses to his questions during his assessment lab introduction, perhaps an indication of the friendly and nonthreatening atmosphere that was perceived. In fact, Peter stated at the beginning, "It's fine if you said yes, or no, or maybe. It's completely subjective. It's an opinion here. In other words, if you think something and you can explain it, that's fine." Many students offered acceptable responses to which Peter replied by restating that response, agreeing with it,



complimenting the student's idea, and moving on. There was only a single instance of a student giving an unacceptable response to a question during this entire assessment lab introduction. Before I show this exchange, I urge the reader to consult the specific research question and data table given in the first mock research report of Appendix C because, as I will argue, this particular student interpreted this question and data differently than was anticipated by the TA, Richard, or presumably, the curriculum designers.

Peter: Is the plan presented going to yield the necessary evidence needed to fully answer the research question? What did you put? [Points to a student]

Student 1: Yes.

Peter: OK, yes. Did anyone say maybe or no?

Student 2: Yeah.

Peter: OK, why?

Student 2: Umm, I think it was asking us specifically for the location in the southern sky and there was only one observation in the southern sky. They looked all over the place, but only once in the southern sky.

Peter: So you're saying they should have only looked in the southern sky?

Student 2: Well, yea, that was the initial question, but umm, based on when it's observed, they only found it once.

Peter: Right, well, the thing is they kind of tracked it month by month. So they said that in this one it was low in the western sky, right after sunset. Then it was in the southwestern, then it was, you know, they kind of tracked it. So they did, I personally think they did take enough data.

There are two points to be made about this exchange. First, students can interpret questions idiosyncratically and give what they believe is an acceptable response only to later have it labeled as unacceptable by a teacher. In this example, the student interpreted the research question to mean that Orion would be found in the southern sky on *lots of occasions*. Hence, this student presumably expected to see data listing Orion's position in the southern sky over many months and believed that his job was to isolate the particular season when Orion was highest, given those southern sky observations. This interpretation is plausible if a student does not have a priori knowledge pertaining to the motions of the constellations throughout the year. That is, the student's response is perfectly consistent with his interpretation of the research question and yet, according to the TAs, Richard, and the CAPER team, is ultimately incorrect because according to Lyon's (2011) description of the first assessment activity, the only inconsistency in the line of inquiry occurs in the final evidence-based conclusion stage (see Figure 4).

Second, and more relevant to the current discussion, Peter's approach for correcting unacceptable responses deviated from Richard's approach. In Richard's approach, after students' reread certain statements from the lab in a particular order, they will be able to generate the acceptable response. In Richard's approach then, the student generates the acceptable response, not the teacher. Peter's interaction with his student in this exchange does not follow this script. Instead, Peter explained his own rationale and told the student the acceptable response. I now turn to Adam's assessment lab introduction which stands in stark contrast to Peter's, both in terms of the atmosphere of the laboratory environment and in terms of Adam's responses to his student's unacceptable responses.

The general atmosphere in Adam's laboratory sessions appeared to be different from Peter's. While Peter generally spoke with confidence and appeared to have established a friendly environment

where all ideas and views were welcome, Adam's assessment lab appeared much different. Adam's students did not generally offer their opinions during the assessment lab introduction. In fact, when Adam initially attempted to elicit responses during this first assessment lab and received only silence, he pleaded, "Come on guys, humor me here." During his assessment lab introductions, Adam typically asked for a show of hands in response to the prelab questions. If most students had the acceptable answer, Adam moved on without comment. This is different from both Peter's and Richard's approach of eliciting verbal responses. During his assessment lab introduction, Adam received only two unacceptable student responses. Each is documented below. In the first exchange, Adam read the question, "Is the plan presented going to yield the necessary evidence needed to fully answer the listed research question?" The acceptable response is yes. Adam asked the class if anyone responded no.

Adam: Anyone say no [to the question]?

Student 1: I did.

Adam: OK.

Student 1: I mean, they got the necessary evidence just to figure out, you know, it wasn't too extreme what they were looking for. Just what constellation is in the sky at that time?

Adam: OK.

Adam's reply to this student's comment was, "OK." He then moved on to the next question. This also occurred three times during Adam's second assessment lab session. During three separate times a student gave an unacceptable answer which Adam did not appear to have a response for. This did not parallel Richard's approach of interacting with students' unacceptable responses by having the student reread certain passages in order to see the error in his/her logic. Regardless of his intent, Adam appeared dismissive of his student's ideas and students were observed to smile and even

chuckle as Adam casually moved on from a student's comment. In another instance during the first assessment lab, Adam asked the class if anyone replied yes to the question, "Have they claimed more than the evidence supports?" The acceptable response is no.

Adam: OK anyone say maybe?

Class: [No hands are raised]

Adam: OK, good. Anyone say yes?

Class: [No hands are raised]

Adam: Ok, good. [Student then raised hand]. You said yes?

Although the transcript, of course, cannot capture emotions, the video clearly shows Adam seemingly dumbfounded that someone could have responded yes to that question. For instance, in response to the student's answer, Adam tilted his head forward, squinted his eyes while pointing at the student, and asked with some suggestiveness, "You said yes?" The way in which he asked the question suggested he was astonished at the student's response. This, also, does not parallel Richard's approach of responding to students' unacceptable responses.

To briefly summarize the nature of TAs' assessment lab introductions, Peter and Adam differed significantly from each other in terms of the level of ease with which they were able to elicit student responses in addition to their general responses to students' comments. For example, while Peter engaged students' comments or asked for clarification, Adam typically just moved on without further comment. However, both Adam and Peter's responses to students' unacceptable responses differed from Richard's model. In Richard's model, the teacher leads the student to the desired response and it is ultimately the student who produces that desired response. However, both Adam and Peter corrected unacceptable answers by giving their own rationale, thus providing the acceptable

response for their students. In the next section, I focus exclusively on the nature of TA-student interactions observed during inquiry labs.

### **TA-student interactions.**

Following the TAs' introductions, students began completing the laboratory activities with their group members. During this time, the TAs interacted with their students by responding to their questions. As I described in the methods chapter, I separately analyzed student's questions and TA's responses. I first present the findings from analysis of students' questions by describing and characterizing the two general types of student problems that preceded all interactions. I then describe and characterize the typical way in which TAs responded during such interactions.

### ***Student problems.***

In this section, I describe two basic types of student problems that preceded all interactions. Generally speaking, students sought the aid of their TA if they (a) generated a response they were unsure was an acceptable answer or (b) were unable to generate a response at all. Further, all interactions between students and TAs were initiated by students. That is, TAs were never observed to interject in a group's conversation unless first asked. As described in the methods chapter, these two problem types were constructed through an inductive analysis of transcripts of video-recorded lab observations. Each problem type is supported by sample passages from video-recorded transcripts of TA-student interactions. Problem types were stable over the entire semester and were evident during the initial, middle, and final laboratory sessions of both TAs. Before I continue, there is one important consideration to discuss. As I will discuss in depth in a later section of this findings chapter, most student groups were able to complete each lab without the assistance of their TA. In other words, over the course of the semester, the majority of interactions were held between a TA and two or three particular groups of students. For example, in one of Peter's lab sessions, one particular

group never asked a single question all semester long. Additionally, during Peter's assessment lab there were no interactions, at all, between Peter and his students. Therefore, it is important to keep in mind that any inferences drawn about these interactions are relevant only to groups that asked questions. Nevertheless, I now describe the two basic types of student problems.

*Is this correct?*

The first type of student problem occurred whenever a group generated a response to a question and sought their TA's approval of that response. These types of student questions did not occur randomly during labs, but instead occurred most often during inquiry labs in phases V and VI (71%) and most often during assessment labs when students believed they had identified the inconsistency in the mock research report (see Figure 6). I now describe all three in more detail and show sample supporting passages.

	Inquiry Lab Phases					Assessment Lab	
Phase of Occurrence	II	III	IV	V	VI	Inconsistency check	Other
Number of questions	5	6	5	27	12	8	2

*Figure 6.* Total number of recorded questions throughout the semester.

This figure displays the total number of questions received by TAs during particular lab phases throughout the semester. For example, there were a total of 27 questions asked of Peter and Adam, during phase V of inquiry labs throughout the entire semester and there were a total of 12 questions asked of Peter and Adam during phase VI of inquiry labs.

Some student groups generated research questions during phase V of inquiry labs and then sought approval of their research question from their TA. For example, during Peter's first lab, one

student asked if, “Is astrology the correct way to know what your sign is?” was a suitable research question. During Adam’s final lab, one student asked if, “From January 1<sup>st</sup> to June 1<sup>st</sup>, which constellations are covered by the sun and thus unable to be observed?” was a suitable research question. All questions in this category contained this general format. Further, as depicted in Figure 6, phase V research questions were a persistent focus of interactions throughout the semester for both TAs. In other words, during any given lab, there were many more interactions focused on students’ phase V research questions than on preceding phases of that particular lab.

Some students generated a phase VI summary and then sought approval of that summary from their TA. For example, during Peter’s first lab, one student read his written summary aloud and asked, “Is that, like, good?” In another example, from Adam’s final lab, one student asked, “Is this an OK summary?” after handing Adam his lab to read. All questions in this category contained this general format. Interactions focusing on summaries occurred only twelve times throughout the semester.

Students responded to a series of prompting questions regarding the consistency between various parts of the mock inquiry report during assessment labs. Some groups generated a response of “no” to some of these questions and then sought their TA’s approval of that “no” response. For example, during Adam’s first assessment lab, one student described where he believed the mock research project was wrong and then asked, “Does that sound about right?” In addition, some groups generated a redesign of the original research project and then sought their TA’s approval of that redesign. For example, during Peter’s assessment lab, one student described his redesign and then asked, “Will that work?” All questions in this category contained this general format. Interactions focused on this occurred fairly frequently during Adam’s assessment labs but not during Peter’s. In fact, there were no student-TA interactions during Peter’s only observed assessment lab.

*What am I supposed to do here?*

The second type of student problem occurred whenever a group was unable to generate a response during some lab phase and sought their TA's assistance. I now show sample student problems to support this contention.

During Adam's Galaxies lab, one group apparently could not think of a phase V research question. One student in this group stated, "I don't know what to ask here." Another student from a different group in Adam's Galaxies lab had a similar problem and stated, "We, umm, cannot think of a question, at all, for this." Although these are not literally questions, these statements are certainly indicative of the group not understanding how to proceed which was the original basis for their separation from the first type of question.

In summary, two types of student problems were evident and preceded all student-TA interactions. First, students sometimes sought the approval of their written responses from their TA. Second, students sometimes sought the assistance of their TA when their group was unable to generate any response to a particular lab question. The majority of interactions during each laboratory session took place between the TA and two or three groups. That is, during any given laboratory session, most groups were able to complete the laboratory activity without the assistance of their TA. Although I provide evidence for this claim in a later section of the this chapter, I mention it to make an important point—the findings from the interactions only apply to groups that actually interacted with their TAs, not the class more generally. Finally, these interactions did not occur randomly throughout labs. For example, during inquiry labs there were more instances of phase V and VI questions than in preceding phases.



### ***TA responses.***

In this section, I describe the response structure of both TAs while responding to the two basic types of student problems described above. These response structures were constructed through an inductive analysis of video-recorded student-TA interactions. Each response structure is supported by sample passages from video-recorded transcripts of TA-student interactions. Response structures were stable over the entire semester and evident during the initial, middle, and final laboratory sessions. I begin by describing Peter's response structure.

#### *Peter's response structure.*

While responding to student questions, Peter never simply told his students the direct answer they were looking for (yes or no). Nor did he simply tell them how to solve a particular problem if they appeared to be unable to proceed (do this to get the answer). He had two basic response structures, depending on the type of student question being asked. First, he described the necessary criteria students could use to determine the acceptability of their responses. Second, he either asked a series of prompting questions or directly told students to think about the problem in specific ways that would, presumably, allow them to obtain an acceptable response. I now describe each of these response structures in more detail.

Peter responded during interactions where students sought approval of their written responses typically by describing the necessary criteria they could use to determine the acceptability of their response. He typically ended by commenting on the acceptableness of that group's response. For example, during the Constellations lab, one group sought Peter's approval of their phase V research question. Peter responded by stating, "Well, if you can take data on it and draw a conclusion, then, you know, that's technically a research question." He followed up by stating, "That's a good way to ask [the research question]." In a similar exchange during the Jupiter's Moons lab, one group sought

Peter's approval of their research question. He responded by stating, "You want to be able to collect data for a question that requires more than just a simple yes or no. I mean, it's kind of, you know, just rinse and repeat if you do that." He concluded by stating, "You might want to think of something a little more big picture." That group, of course, left with the idea their research question was unacceptable. In another example from the Constellations lab, another group sought Peter's approval of their phase V research question. He responded by stating, "If you can answer the question and you can, you know, make a reasonable procedure to get the data, then that's perfectly valid, I would say." The overall structure of Peter's response to questions that sought his approval was clear. He described the necessary criteria that defined an acceptable response and followed up by giving his opinion of the acceptability of their response. Peter gave these types of responses often throughout the semester as students frequently sought the approval of their phase V research questions.

Peter responded to groups who were unable to generate a response by asking a series of questions designed to help the group think about the problem in a way that could lead them logically towards an acceptable response. Sometimes, however, Peter directly told the group the important things to think about. He would then usually tell the students the important pieces of that exchange so they focus in on what he considered to be important to determine the acceptable response. For example, during the Constellations lab, Peter responded to a group that was apparently unable to generate a suitable phase V research question. Their interaction is presented below.

Peter: If you look back at the rest of the lab, what kinds of things have they been observing?

Student 1: Stars.

Student 2: Constellations.

Peter: Stars, constellations, what about them?

Student 1: Their movement.

Student 2: Their movement.

Peter: Their movement. Where they are. When they are in certain places. When they aren't in certain places.

Peter asked the students questions about previous parts of the lab with the intent of helping the group move towards generating an acceptable response. These students were then able to generate a research question which ended up earning full credit. In another example, Peter responded to a group that was also apparently unable to generate a response to the phase V research question. The following exchange occurred during the Galaxies lab.

Peter: What can you actually observe? You know, what kind of data can you take? Like, what kind of questions have they asked you so far?

Student: Different colors.

Peter: Different colors.

Student: Sizes.

Peter: Different sizes. Distributions. So try to use those in a different...So what you should try to do is identify what you can actually measure and then think of a question about it.

In this exchange, Peter again asked the student questions about previous parts of the lab with the intent of helping him move towards generating an acceptable research question. He then concluded by drawing the student's attention to the importance of looking back at previous phases. His final piece of advice to "identify what you can actually measure and then think of a question about it" appears to be backwards from the common view of scientific inquiry as beginning with a question or hypothesis (see NRC, 2012). The overall structure of Peter's response to questions where students were unable to generate a response was clear. He asked questions designed to help them think about the problem in a way that might lead them towards an acceptable response. Sometimes, instead of

asking questions, Peter would simply tell the students what to think about to determine an acceptable response. He typically ended these interactions by drawing the group's attention to the important part of that exchange. Overall, both of Peter's response structures were consistent and remarkably stable across the entire semester. I now compare and contrast these with Adam's response structures.

*Adam's response structures.*

Adam interacted with his students throughout the semester by responding to their questions. As described earlier, two different types of student problems were evident. Adam responded differently to both types. First, he would either respond with a quick "yes" or "no." Second, he would focus students' attention on information he presumably considered important for answering the question. I now show examples of both responses.

During interactions where students sought his approval of their group's generated response, Adam typically responded by stating "yes" or "no." He did not typically follow up with further comments. For instance, when groups asked for approval of their phase V research questions, Adam stated "Yea, sure" or "I think that is reasonable" or "Yea, go for it." He did not typically offer follow up comments during these terse exchanges. This stands in stark contrast to Peter's approach of responding to these types of questions.

Adam responded to groups who were unable to generate a response by focusing their attention on information he presumably considered important for leading them to an acceptable response. He did not typically give the group the acceptable answer but rather told the group the relevant information they could use to generate an acceptable response. This is similar to Peter's strategy, at least superficially. For example, when one group could not generate a phase V research question for the Galaxies lab (Appendix B), they called Adam over. Their exchange is below.

Student 1: We don't know what to ask.

Adam: You don't know what to ask.

Student 1: I feel like everything's already been asked.

Adam: Well, not everything.

Student 1: About galaxies.

Adam: Not everything. So you've been introduced to the different characteristics that a galaxy can have, right? They can be nearby. They can be far away, based on size. They can be different colors. Or it can be spiral or round. Right? Yea?

Student 1: Yea.

Student 2: Can we do like, which ones are spiral and which ones are round?

Adam: So, yea, if you look for some, if you want to try and look for some relation between the numbers of the sort of things, that would probably work. That work?

Student 1: We'll figure it out.

As a matter of fact, this particular group ended up writing the research question, "How many galaxies are spiral and how many are round?" I will discuss the problem with these types of research questions in a later section. Suffice it to say that Adam's response to this particular group's question was typical of his responses to groups that cannot generate an answer. He told the group the relevant information required to generate an acceptable response to the question.

In summary, both TAs responded to their students' questions. Both TAs attempted to lead their students towards acceptable responses during interactions. However, there were noticeably different approaches towards achieving that end. While Adam would respond with a terse approval or disapproval towards groups seeking his approval, Peter told group the necessary criteria they could use to determine the acceptability of their responses. Both TAs responded similarly towards groups who were unable to generate responses to lab questions. Both TAs implicitly assumed there were

acceptable and unacceptable questions and then led their students towards the acceptable responses. However, their approaches differed. Peter typically engaged in Socratic questioning while Adam simply told his students what to think about. During Peter's interaction of this sort, as I demonstrated, student's ideas were discussed. In contrast, during Adam's interactions only his ideas were discussed. In both cases, however, there is an acceptable answer and the TA leads them towards that answer, Peter through questioning and Adam through telling.

### **Enactment of grading scheme.**

Like introductions, Richard described grading as an obligation TAs must fulfill and hence constituted another rule he expected his TAs to follow. Richard communicated the basics of the grading scheme during the third and fourth TA meetings. As he admitted during several informal meetings with me, as captured by my written memos, Richard did not believe the CAPER team offered him any insight into how their curriculum materials should be assessed. In fact, this message was directly communicated to the TAs during the fourth TA meeting when Richard stated the following.

I'm sorry that we kind of have to hash this out [the grading scheme], but I was talking to [one of the curriculum designers] and he was like, 'well, I don't know what the grading scheme is supposed to be, just make something up that makes sense. I mean, he basically said that once you read through some of the labs, the grading scheme will be obvious. (TA Meeting, 9/13/2011)

Because Richard did not receive guidance on how CAPER's laboratory materials were to be assessed, he generated a grading scheme on his own. He would communicate this scheme during the next TA meeting.

In Richard's grading scheme (see Figure 7), each student of a particular group would be assigned two separate grades for each laboratory activity. First was a group grade based on a random grading of one group member's phases I through V. Richard reasoned that groups would work together most during these phases and hence should be graded together. Consequently, he requested his TAs to tell their students that all work in phases I through V should be identical because one member's work would be graded randomly. The second grade each student received on a particular lab was an individual grade based on the student's written response in the summary phase VI. Richard reasoned that students should work individually on their summaries and expected his TAs to communicate that message to their students during laboratory sessions. The allocation of points is shown below.

Phase	I	II	III	IV	V	VI
Points per phase	0 or 3	0 through 1 $\frac{1}{2}$ point increments	0 through 1 $\frac{1}{2}$ point increments	0 through 1 $\frac{1}{2}$ point increments	0 through 4 $\frac{1}{2}$ point increments	4 through 10 1 point increments

*Figure 7. The grading scheme.*

In this grading scheme, students can earn zero or three points on phase I, which was the prelab. Students can earn zero to one point on phases II through IV, each with one-half point increments. Students can earn zero through four points on phase V, with a one-half point increment. Finally, students can earn four to ten points on phase VI, with a one-point increment. Therefore, students can earn a maximum of twenty points. Half the total possible points came from phases I through V (a group grade every member earns) and half came from the phase VI summary (an individual grade). Richard never described the rationale for this point system.

*Allocation of points.*

Richard described the rubric he expected TAs to use while grading their students' labs. This rubric was written on the white board for TAs to observe and take note of. According to Richard, phase I (prelab) was to be graded immediately after the TAs gave their introductions. Students could earn zero or three points on their prelab based only on completion, not accuracy.

TAs assigned points for phases II through IV by selecting one lab randomly from the group. This lab would be graded and assigned as the group grade to every student in that group. Each of these phases could earn a maximum of one point regardless of the number of questions in these phases. Responses to a phase that were left "blank" earned zero points. Responses to a phase that contained "scribbled or half-assed" explanations earned half a point. Responses to a phase that contained "beautiful" explanations earned a full point. Richard never discussed student responses that were to be labeled as "half-assed" or "beautiful" and the TAs did not ask for further clarification. It was assumed all student's responses for these phases would be identical and hence justification for assigning all students the same grade.

Each phase V inquiry lab contained the same four questions (See Galaxy lab, Appendix B for an example). TAs were to use the same randomly chosen lab during this phase's grading. Hence, each question I phase V would be worth a maximum of one point, with one-half point increments. Richard assumed all student's responses for these phases would be identical and hence justification for assigning all students the same grade.

For phase VI, all summaries were to be read and graded individually for each group. According to Richard, each student was to be assigned a numerical, integer grade ranging from four to ten. Richard stated he believed TAs would see all possible grades for summaries. Richard ended



this third TA meeting by requesting that TAs find examples of “good” and “bad” responses to phase VI inquiry labs and to bring those sample responses with them to the fourth TA meeting.

During the fourth TA meeting, Richard asked TAs to read their student’s written work. This period lasted around 35 minutes. During this time, TA shared with the group their “good” and “bad” student responses. Richard ended each with “I’d give that a 10, right? That clearly shows good understanding” or “I’d give that a 6, the student left out critical stuff, right?” Richard did not describe the justification of numerical grades. He only listened to the sample student responses and replied with a grade and a quick comment. TAs were not offered any solid, tangible criteria from which they could more easily discriminate between responses. This meant that a minimal amount of time was spent guiding TAs’ assessment procedures.

***TAs’ use of grading scheme.***

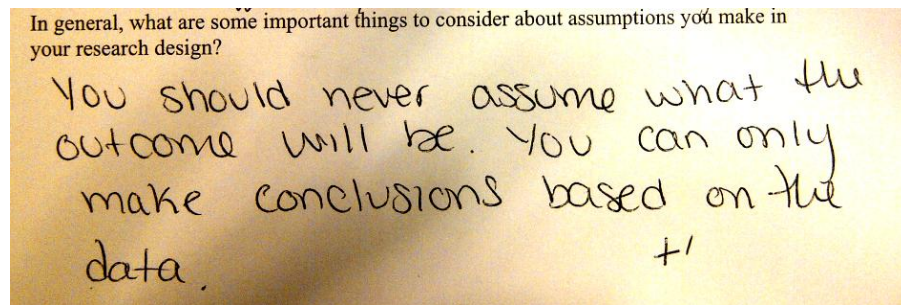
The TAs used the grading scheme provided by Richard to assess their students’ inquiry and assessment labs. Out of the 136 inquiry labs that Adam graded, he gave an average score of 19.3 out of 20 possible points (96.6 %). Out of the 44 assessment labs Adam graded, he gave an average score of 19.5 out of 20 possible points (97.5%). Similarly, out of the 130 inquiry labs Peter graded, he gave an average score of 17.5 out of 20 possible points (87.5 %). Out of the 51 assessment labs he graded, he gave an average score of 19 out of 20 possible points (95%). In grading phases II through IV, the TAs graded similarly; all groups received full credit and written comments were typically nothing more than a check mark. It was only in phase V and VI that the TAs tended to encounter unacceptable responses from the students.

Through an inductive analysis of students’ graded labs, I generated one general theme: When students lost points they were provided with either no rationale or else with a rationale that appeared to be of limited use for students. More specifically, of the 136 inquiry labs that Adam graded, 84 of

them lost no points, 29 of them lost points but were provided with no rationale, and 23 of them lost points and were given comments that appeared to be of limited use. Similarly, out of the 44 assessment labs Adam graded, 23 of them lost no points, 9 of them lost points but were provided with no rationale, and 12 of them lost points and were given comments that appeared to be of limited use. I found no instances of Adam giving any student comments that could be used to understand neither why points were lost nor how future responses could be differently worded.

Peter had a similar grading pattern. Of the 130 inquiry labs Peter graded, 86 of them lost no points, 16 of them lost points but were provided with no rationale, and 12 of them lost points and were provided with comments that appeared to be of limited use. Differently from Adam, however, 16 of Adam's graded lab contained comments that could potentially be of use for students. I show examples of both TAs grading habits below.

The following figures are examples of Peter's grading practices. In both cases, a student loses points but is provided with no rationale.



*Figure 8. Peter's grading of an assessment lab.*

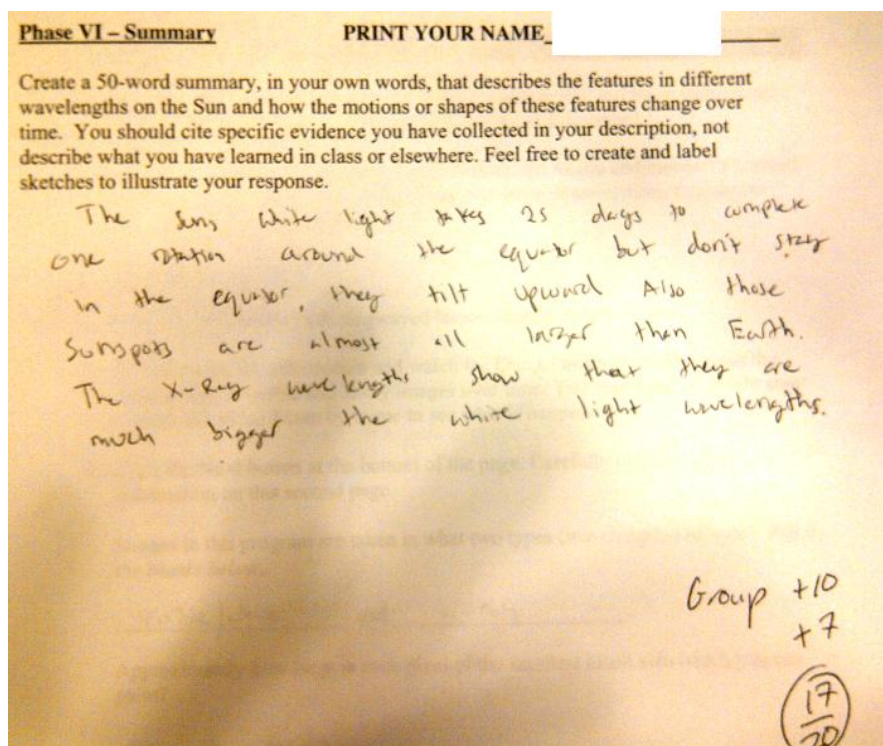


Figure 9. Peter's grading of a phase VI summary.

In Figure 8, a student lost one point out of a possible two points on this particular question on the assessment lab and is given no rationale. In Figure 9, a different student lost three points out of 10 possible points for his particular response to this phase VI summary and is given no rationale. I now turn to examples of Adam's grading practices.

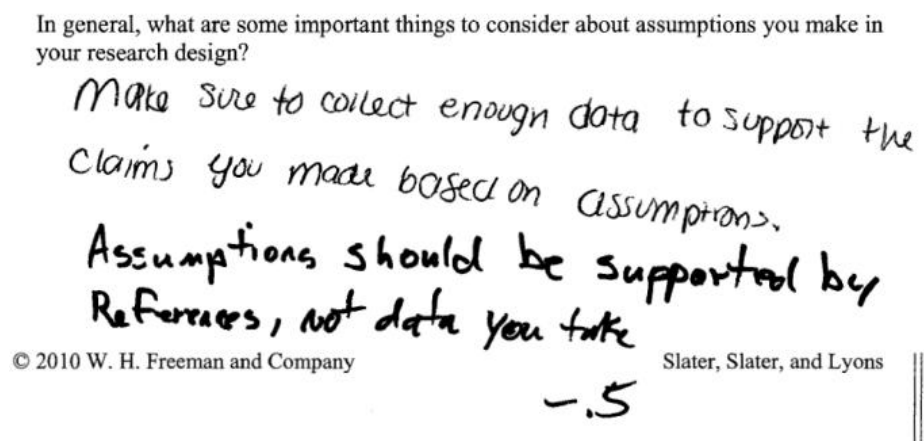


Figure 10. Adam's grading of an assessment lab.

ENGAGING IN ASTRONOMICAL INQUIRY | 27

Phase VI – Summary      PRINT YOUR NAME \_\_\_\_\_

Create a 50-word summary, in your own words, that describes which constellations are visible at night and how this changes over the night and over the year. Feel free to create and label sketches to illustrate your response.

Over the night, constellations that are opposite the Sun at noon will be ~~also~~ visible in the night sky. This is because the earth ~~rotates~~ <sup>revolves</sup> ~~around~~ a day ~~every~~ showing what is opposite the sun. 6 months from a specific day, however whichever constellation that was behind the sun 6 months ago will be visible in the night sky. This is because the earth ~~revolves~~ rotates the sun once per year.

more info!

Figure 11. Adam's grading of a phase VI summary.

In Figure 10, a student lost one-half a point out of two possible points and though is provided with a comment, it is unclear how this student could use this comment to correct her work. In Figure 11, a different student lost two points out of ten possible points and though is provided with a comment, it is equally unclear how this student could use the comment to correct his work.

It should be reiterated that the average lab grade in both Peter and Adam's laboratory sections was quite high (above 87%). Yet, the labs in which students did lose points were either not accompanied by a clear rationale or else were provided with a comment that appeared to be of limited use. No student was observed to question their grade during observed laboratory sections. It could be the case that because the points students lost were minor, students did not feel compelled to ask their TAs for a clear rationale.

### **Most labs completed without TA's help.**

The majority of groups were able to complete their laboratory activities without the assistance of their TA. A careful inspection of Figure 6 reveals that there were a total of fifty-five (55) videorecorded inquiry lab interactions in total for both TAs throughout the semester. Each laboratory section possessed seven student groups. As I described in the previous chapter, I videorecorded Peter's inquiry laboratory sections on four separate occasions and videorecorded Adam's inquiry laboratory sections on three separate occasions. Figure 12 displays the number of times particular groups asked questions during videorecorded inquiry laboratory sections for both TAs. This figure displays the number of questions asked by a particular group during each lab section. For example, during the Adam's Galaxies lab, group 4 asked two questions while group 7 asked zero questions.

As can be seen in Figure 12, only a few student-groups asked questions throughout the semester. This means that most groups did not have a significant number of interactions with their TA for the duration of the semester, as claimed. There could be a number of possible explanations for this occurrence. First, it could be the case that the laboratory activities were challenging, but students were able to complete them because they possessed highly developed inquiry skills. Second, it could be the case that the lab activities were challenging, but because students were not typically penalized for their responses in terms of point-deductions (as demonstrated in the previous section), students' responses were simple. Third, it could also be the case that the laboratory activities expect simple responses and students were able to generate them. I will argue for explanations two and three in the Implications chapter.

	Lab	# Constellation Questions	# Galaxies Questions	# Sun Spots Questions	# Jupiter Questions	Total # Questions
Peter's Lab	Group1	1	0	1	0	2
	Group 2	1	0	1	0	2
	Group3	0	0	1	0	1
	Group 4	0	0	0	0	0
	Group 5	3	2	2	3	10
	Group 6	2	3	1	1	7
	Group 7	1	0	1	0	2
Adam's Lab	Group1	1	1	0	-	2
	Group 2	2	1	1	-	4
	Group3	4	3	2	-	9
	Group 4	5	2	3	-	10
	Group 5	2	0	1	-	3
	Group 6	1	0	0	-	1
	Group 7	2	0	0	-	2

*Figure 12.* Number observed questions per lab per group

### **Summary of enactment phase.**

The TAs were responsible for the enactment of the new laboratory curriculum. The enactment phase began with the first laboratory session during week two of the semester and concluded with the final laboratory session during the fourteenth week of the semester. Data used to describe and understand the enactment phase came from interview transcriptions, videorecorded laboratory

observations, audiorecorded TA meetings, and student's written responses to labs. I constructed several themes through an inductive analysis of this data.

First, Richard established the professor-TA dynamic during the first TA meeting. During this first meeting, Richard described the rules TAs were expected to follow. This included giving specific introductions tailored to his choosing, interacting with students in a particular manner, and grading student's laboratory work with a grading scheme constructed and provided by Richard. Though Richard was generally friendly and approachable, it was clear these rules were nonnegotiable. Hence the dynamic that formed was of a procedural nature—TAs' followed procedures and guidelines set out for them by Richard.

Second, Richard implicitly communicated the view that some of the rules required more attention from them than others. For instance, Richard spent the majority of TA meetings modeling introductions to labs he expected his TAs to give. He took the time to carefully point out things they should inform their students of. During their laboratories, TAs' introductions lasted only a minute or two. In contrast, very little time was spent preparing TAs for the interactions they would have regularly with their students as they worked through the laboratory activities.

During observed laboratory sessions, the majority of groups were able to complete the laboratory activity without the assistance of their TA. TAs interacted with their students by responding to their questions. Through an inductive analysis of video recorded interactions between TAs and their students, I described two basic types of student problems that preceded all interactions. First, sometimes groups generated responses to laboratory questions and sought the approval of their TA. Second, sometimes groups were unable to generate responses to laboratory questions and sought the assistance of their TA. Both TAs responded to their student's problems. In response to the first type of student problem, Adam directly responded with approval or disapproval of their written

responses without further comment. In response to the second type of student problem, Adam typically told the group the information he considered important for the group to be able to generate the acceptable response. In contrast, in response to the first type of student problem, Peter typically described the criteria the group could use to evaluate the acceptability of their response. In response to the second type of student problem, Peter typically questioned or told the group the information he considered important for them to generate an acceptable response to the lab question.

The types of student problems and the structures of TA responses were indicative of the overall dynamic established during the first laboratory session and, as argued, was maintained throughout the course of the semester. There were acceptable and unacceptable responses to all questions in the lab and the goal was to generate the acceptable responses or be penalized by the TA. If groups could not generate a response or were not sure of the acceptability of their response, they sought their TA's approval or assistance. In response, TAs did not directly give students the acceptable answer but presented them with information or questions which, presumably, groups could use to generate the acceptable response.

The grading scheme was completely determined by Richard. During TA meetings, Richard communicated this grading scheme and expected his TAs to follow it. However, little guidance was given to TAs to discriminate between different types of student responses. Moreover, analysis of graded labs revealed unclear grading rationales. Students who lost points were unaware why they had lost points. Additionally, most student-groups were able to complete their laboratory activities without the assistance of their TA. I will discuss the implications of these findings in detail in the next chapter. First, however, I discuss the impact of the learning environment on students' understanding of the nature of scientific inquiry as well as other general findings related to the perceived success of this learning environment.



### **Impact of the laboratory curriculum**

In this section I provide evidence that (a) students did not develop informed views of the nature of scientific inquiry, as measured by VOSI, (b) TA's believed they were successful and that the laboratory learning environment was a success, and (c) the professor believed that the laboratory learning environment was unsuccessful based on students' negative end-of-semester course evaluations.

#### **Impact of curriculum on students' views of the nature of scientific inquiry.**

I administered the VOSI instrument before and after implementation of the new curriculum to investigate the impact of the new laboratory learning environment on students' views of the nature of scientific inquiry. By the end of the semester, I had collected 42 pre- and post-VOSI sheets from students (20 from Peter's lab and 22 from Adam's lab). The major result from analysis of pre and post VOSI data from students of both TAs is an observation of no change toward informed views. As judged by their written responses to the VOSI instrument, no student in either laboratory section developed more informed views of the nature of scientific inquiry after the curriculum. All students who possessed mainly naïve views prior to the curriculum maintained naïve views after the curriculum. Two students, one from each TA, possessed mainly informed views prior to the curriculum and both students maintained those informed views after the curriculum. No students were observed to move from mainly naïve towards mainly informed. I show sample responses from several students' pre and post VOSI sheets from each TA below to justify this claim.

#### **Naïve views of NOSI.**

I show below sample responses from four students. These students' pre- and post- test NOSI profiles were judged to be mainly naïve. I chose to sample different parts of each student's VOSI sheet rather than show their entire responses to the complete VOSI questionnaire. Therefore, although

below I show only part of each student's VOSI sheet, this should not be taken to imply that only those presented sections were used to evaluate that student's views of NOSI.

Sarah completed the VOSI sheet before and after implementation of the curriculum. Her views as expressed in writing were judged to be mainly naïve. In her pre-test, Sarah described what the word data means in science: "Data is the results or conclusions that you collect from a scientific experiment. It's usually numbers." She continued, describing the main differences between data and evidence: "Data could prove or disprove a point so it may not be evidence in the scientists favor. It's also possible that evidence may not be obtained from the data because the data could be misleading." The belief that data are the results one collects from an experiment is a typical response from a person with naïve views of NOSI. Data are just the raw information collected from a study, which could be numbers or observations (i.e., can be quantitative or qualitative) while evidence is constructed, with said data, in light of a particular research question or hypothesis (Schwartz et al., 2008). Further, her description of data proving or disproving a point also is indicative of naïve views of NOSI. In Sarah's post-test she maintained these naïve views. She described data as "the evidence collected to prove or disprove a hypothesis from a scientific experiment." She continued, describing again the main difference between data and evidence. "Data is usually numbers but is also just evidence." Her view that data is evidence is typical of an individual who possesses naïve views of NOSI (Schwartz et al., 2008). Her responses to the remaining questions from the VOSI sheet were also indicative of naïve views of scientific inquiry. In other words, the responses to her two VOSI sheets were consistent with those who possess a naïve view of NOSI.

Bryan completed the VOSI sheet before and after implementation of the curriculum. His views as expressed in writing were also judged to be mainly naïve. In his pre-test, Bryan described why he believed all scientists needed to follow the so-called scientific method. "I believe this method

of making a hypothesis and going through the motions provides the whole basis for conducting scientific research. If no hypothesis is made, a person is merely conducting research.” In Bryan’s view, unless scientists generate a hypothesis, they are not engaged in scientific research, merely research. The view expressed by Bryan in his pre-test is consistent with an individual who possesses a naïve view of NOSI. In his post-test, Bryan maintained these naïve views. Bryan again articulated his views on the scientific method. “Scientists must follow the scientific method because it allows them to take every step of the experiment carefully to explore the hypothesis. If you don’t follow the scientific method and don’t make a hypothesis then your [sic] not really doing science.” Bryan’s view that science is done exclusively through experimentation and hypothesis-testing is typical of an individual who possesses a naïve view of NOSI. His responses to the remaining questions from the VOSI sheets were also indicative of naïve views of NOSI. In other words, the responses from his two VOSI sheets were consistent with those who possess a naïve view of NOSI.

Jessica completed the VOSI sheet before and after implementation of the curriculum. Her views of NOSI were judged to be mainly naïve. In her pre-test, Jessica described a scientific experiment as “one in which you test a theory to try and prove it right.” This general statement is typical of students who possess naïve views of NOSI. She continued, describing what the word data means. “Data means a series or collection of numbers that you get from running your experiment. They help prove your theory.” Like before, this statement is also indicative of an individual who possesses a naïve view of NOSI. She also commented on the difference between data and evidence by stating “data and evidence are the same thing. They help you prove or disprove your theory.” These statements, together, are indicative of an individual who possesses a naïve view of NOSI. Her responses to the remaining VOSI questions were also judged to be mainly naïve. In her post-test, Jessica maintained those naïve views. She again described a scientific experiment as “when you test a

theory or hypothesis to prove it correct or not.” Like before, Jessica appears to possess a naïve view of scientific experiments. Also like before, she described the difference between data and evidence in the following way. “Data in science means hard facts and numbers to test the experiment.” These views, like the ones she expressed during the pre-test, are indicative of a naïve view of NOSI. Finally, she again described that there is no difference between data and evidence. Overall, her responses to the remaining questions were also indicative of a naïve view of NOSI.

Colleen completed the VOSI sheet before and after implementation of the curriculum. Her views were judged to be mainly naïve. In her pre-test, Colleen described the hypothetical investigation of question 2 in VOSI as an experiment. She wrote, “Yes, this can be considered an experiment because the person collected evidence to come up with a conclusion.” Colleen appears to possess the naïve and general view that one collects evidence directly from an investigation and that if that evidence is used to “come up with a conclusion” then an experiment has been conducted. This is consistent with a naïve view of a scientific experiment. During her pre-test, Colleen also described that scientists must follow the scientific method because “in order for someone to prove a hypothesis one must follow all of these steps in order to show how they proved their conclusion.” This statement is consistent with the naïve view that all scientists must setup experiments and follow the set of golden rules to generate real knowledge. Colleen responded to the remaining question in a way that suggested she possessed a naïve view of NOSI. On her post-test, Colleen maintained those naïve views. She, again, believed the hypothetical investigation described in question 2 of VOSI was an experiment. She stated “Yes, its [sic] an experiment because he collected evidence and proved that what animals eat depends on their teeth structure.” As before, Colleen appears to naively believe that scientists collect evidence and that if evidence is used to generate a conclusion, then that scientist has conducted a scientific experiment. In addition, Colleen again naively described the scientific method

as something that all scientists must follow. She stated, “in order to receive a conclusion from a hypothesis, these exact steps must be followed to have accurate data.” In this statement, Colleen naively expressed the view that all scientists must follow the rigid scientific method to generate knowledge. Holistically, Colleen’s post-test VOSI profile was judged to be mainly naïve.

In summary, I have presented four sample student responses (out of a total of 42) from both students’ pre- and post- VOSI questionnaire that were judged to be mainly naïve. Out of the 42 students, a total of 40 of them were judged to possess mainly naïve views of NOSI. I now turn towards the only two students who were judged to possess mainly informed views of NOSI.

### **Informed views of NOSI.**

I show below sample responses from two students. These students’ NOSI profiles were judged to be mainly informed. I chose to sample different parts of each student’s VOSI sheet rather than show their entire responses to the complete VOSI questionnaire. Therefore, although below I show only part of each student’s VOSI sheet, this should not be taken to imply that only those presented sections were used to evaluate that student’s views of NOSI.

Laura completed the VOSI sheet before and after implementation of the curriculum. Her views as expressed in writing were judged to be mainly informed. In her pre-test, Laura described a scientific experiment in the following way.

A scientific experiment is a specific type of study which tries to evaluate a hypothesis. In a scientific experiment, one variable is being tested and all other variables are being controlled (as much as possible). An example of an experiment would be to test the effectiveness of a type of bleach. It would involve using different types of bleach on identical stains and measuring which was the most effective. (Laura, pre-VOSI)

Laura's description of a scientific experiment as evaluating a hypothesis by testing one variable while holding all others constant is consistent with an informed view of NOSI. With this conception of a scientific experiment, Laura then discussed why she thought the description provided in question 2 of the VOSI questionnaire was not experimental in nature.

This person's investigation is not an experiment. This is because no variables were manipulated or controlled. The research simply observed pre-existing differences. A better term for this investigation would be a naturalistic observation. (Laura, pre-VOSI)

Laura's description of the investigation as a naturalistic observation rather than a scientific experiment is also consistent with an informed view of NOSI. Laura's responses to the remaining questions were also judged to be mainly informed and hence she was judged to possess a mainly informed view of NOSI. During her post-test, Laura maintained these informed views. While describing a scientific experiment, she described it in the following way.

A scientific experiment is a type of study in which a variable is manipulated to determine a cause and effect relationship. A good experiment uses a large sample size and has controls. An example of a scientific experiment would be testing the efficacy of a drug. One group would be given the drug, one group would be given a placebo, and one group would be given nothing. Then you would observe a decrease in symptoms. (Laura, post-VOSI)

Laura's description, again, is consistent with an informed view of NOSI. She, again, recognized that the hypothetical investigation presented in question 2 on the VOSI sheet is not an experiment because "no variable was manipulated by the researcher, the research merely observed existing things." Her responses to the remaining post-VOSI test were consistent with an informed view of NOSI. In summary, the responses from Laura's two VOSI sheets were consistent with an individual who possessed a mainly informed view of NOSI. Because she possessed these mainly

informed views during her pre-test, I cannot claim the laboratory learning environment caused her to develop towards more informed views of NOSI.

Greg completed the VOSI sheet before and after implementation of the curriculum. His views were judged to be mainly informed. In his pre-test, Greg described the hypothetical investigation presented in question 2 of the VOSI sheet as non-experimental.

To be an experiment, one would have to have a hypothesis and try to find a cause and effect relationship between some defined variables. You normally manipulate one variable and keep others constant and observe change in the system. This investigation did not due [sic] this and so isn't experimental. (Greg, pre-VOSI)

In this passage, Greg's view of a scientific experiment as used to develop cause and effect relationship by manipulating and controlling variables is consistent with an informed view. Further, using this idea, Greg stated that the hypothetical investigation is not an experiment. Greg also discussed the difference between data and evidence in a manner consistent with an informed view.

Data means anything that you collect from your investigation. It could be numbers from an experiment or observations made of some naturalistic setting....Data and evidence are not the same. Data is what you collect from your investigation. Evidence is when you take that data and interpret it in terms of your hypothesis. Evidence is used to form conclusions. (Greg, pre-VOSI)

In this passage, Greg described the distinction between data and evidence in a way that is consistent with an informed view. Greg also described how he believed scientists knew they were ready to make their research results public.

It depends on the research. This is something I'm dealing with currently with my research. If your [sic] conducting an experimental investigation, you generally be sure you have sufficient

statistical power and that you've run the appropriate statistical models to analyze your data.

You also don't just do this alone. You show what you've done and what you're going to do to your peers. You'd then interpret your results in light of others [sic] work. (Greg, pre-VOSI)

In this passage, Greg generally demonstrated he possessed a mainly informed view of the justification of scientific knowledge. Although he only described the justification process for an experimental study, he does so in a manner consistent with an informed view. Greg responded to the remaining question in a way that suggested he possessed mainly informed views of NOSI. Greg maintained these informed views on his post-test. Greg, again, described an experiment as “when you manipulate variables while holding others constant to establish a cause and effect relationship.” He again correctly described the hypothetical investigation in question 2 of the VOSI form as non-experimental. Greg responded to the remaining question in a way that suggested he possessed mainly informed views of NOSI. In summary, Greg's two VOSI sheets were consistent with an individual who possessed an informed view of NOSI. Because he possessed these informed views during the pre-test, I cannot claim the laboratory learning environment caused him to develop towards more informed views of NOSI.

In summary, I have presented two sample student responses from both students' pre- and post-VOSI questionnaires. These students were judged to possess mainly informed views of NOSI. The remaining 40 students in this laboratory section were judged to possess mainly naïve views of NOSI, as measured by VOSI. According to the CAPER team and associated, published dissertations, their labs improve student's understandings of NOSI. Richard adopted these materials and expressed a hope that student's would “learn something about the process of science,” essentially adopting the goals of the designers. The goal was not met by students of either TA as measured by the VOSI



instrument. No students transitioned towards more informed views. Rather, their views both pre- and post-test were indicative of mainly naïve views of NOSI, as measured by VOSI.

### **TAs' perception of laboratory learning environment's success.**

Both TAs believed that the laboratory learning environment had been a success and were generally appreciative of the design and structure of the labs. In what follows, I provide passages from their interviews to provide support for these claims.

Peter stated that lab was “running smoothly” and that he hadn’t yet run into “any big issues” during his final interview. Peter believed that the lab activities were a success and even pondered how they could be translated into other settings.

I think in the general case [the labs] worked very well. I’d be really interested to see how the [backwards-faded scaffolding] labs apply to a lab that might end up being a little more computational. For example, an Ohm’s Law lab or something like that. (Interview 3)

Peter continued by professing his appreciation of the lab activity’s structure.

In general I enjoyed the labs a lot. I think the formats worked really well. The format of the lab, in general, made it easier on the TAs. So I’m pretty appreciative of the design. I guess the only criticism I would say is to go through and maybe do a little bit more peer reviewing in the editing. Just to look for some of those questions that might be a little bit ambiguous.

(Interview #3)

Peter believed that the lab activity’s structure worked well and offered only minor criticisms. His optimistic attitude was apparent during all interviews and during casual conversations both with me and with other teaching assistants. He also maintained that the entire backwards-faded scaffolding (BFS) framework, if “performed, executed properly,” would be preferred to over more traditional

laboratory experiences. Peter also believed that he was a successful TA and based this claim on reflection of his students' lab grades.

I think [the students] grades have been pretty good actually so their success hopefully is reflected on my success a little bit. I mean, if I was being a [bad] TA, I imagine that their grades would be a little lower. (Interview #3)

According to Peter, his positive self-evaluation came from examination of his students' high grades. Peter also believed his students learned about "the scientific process" regardless of whether they were aware of it or not.

[The labs] are getting the students into the idea of, you know, answer basic questions first and then, you know, kind of build up to asking a bigger question. I think that the labs have probably taught them that on a subconscious level. I don't know how many of them have actually said, you know, I have a better understanding of how research actually works now, but I think going through the process has certainly helped them with their problem solving skills in general and their approach to things. (Interview #3)

Peter not only believed that the lab activities helped students understand the process of scientific inquiry, but he believed so regardless of whether they were cognizant of it.

I think that the labs were designed well. So I think whether [the students] realized it or not, they probably did learn quite a bit going through these labs. So I think that throughout the labs, I think the labs have helped to reinforce the core concepts and then to get them to think about the bigger picture a little bit more. (Interview #3)

Peter believed that the purpose of the laboratory activities was to engage students' in scientific inquiry. Moreover, he judged the labs to be a success at that end and believed that the labs achieved these ends even if students were not explicitly aware of it.

Adam reiterated several of the same points as Peter. Adam believed that the laboratory activities were successful and that their method was effective.

I think the method is fairly effective and, you know, it formed their thinking process. Towards the end they could get through phases two through four pretty darn easily without asking too many questions. They could do the conclusion and they could, like, think about if there was, you know, bias in a question or whatever. And so I think that that particular method was fairly effective. (Interview #3)

Adam's belief that the design of the laboratory activities was effective was based on student's written responses of the summary phases of the activities. Adam's belief that the design of the laboratory activities was effective was also evident as he voiced his opinion for a hypothetical choice to teach either astronomy using their current design or a physics laboratory, which was his true passion to begin with and was more comfortable with the concepts.

If given the choice between a physics lab and an astronomy lab, I think I'd actually prefer the astronomy lab. They are really well structured and I've heard from other TAs in other classes that some of the labs are really poorly structured in other physics labs. But also, the subject matter is very interesting and all of my students with a few infrequent exceptions are very well behaved and very courteous and just a lot of fun to be around. (Interview #3)

In spite of Adam's preference of physics above astronomy, he maintained that he would prefer to teach the astronomy laboratory. Though he did state that students would find the subject matter within astronomy fascinating, he believed that the structure of the astronomy laboratory environment was the most enticing part.

Adam also believed he was generally a successful TA and, like Peter, based this belief on the work of his students.

I think I've been fairly successful in that the students have gotten more proficient at doing the lab over the course of the semester. I think they genuinely, you know, they all didn't enjoy doing the labs, but they seemed to be happy enough in the lab. And as we were going on there were less students who were, you know, like really confused so I guess, in that respect, I was a fairly successful TA. (Interview #3)

Adam considered his teaching a success because his students were able to complete the labs without incident.

In summary, both TAs believed that the laboratory learning environment was a success and further believed they had been successful TAs based on the lack of student questions and their students' subsequent high grades. They further believed that students, if only subconsciously, have gotten into the habit of forming a research question, collecting data, and constructing evidence-based conclusions—that is, engaging in inquiry.

### **Richard's perception of the laboratory learning environment's success.**

Richard, in contrast to the TAs, did not believe that the laboratory learning environment had been successful based on students' end-of-semester course evaluations. The course evaluations were from all students in the course, not just Adam and Peter's students. Although I cannot demonstrate that the patterns found in Adam and Peter's lab also occurred in the labs of other TAs, it may be that this uniform criticism implies that this may be the case. The most common statements of the labs were "tedious" and "busy work." Richard reasoned that "they [students] probably didn't like the fact that everything that they were doing was on the computer. Right? I mean with the BFS labs, students are sat collecting data at a computer. They don't like that."

Richard also voiced a similar concern prior to implementation of the curriculum. He once again stated that he had been taking a "leap of faith" implementing these new labs. He elaborated on

what he had meant by a “leap of faith,” a term he used during the first interview, and why he believed he had been taking one.

I think it’s because the labs were unproven. I went wholesale with these labs based on the BFS paper which seemed to demonstrate that there was something behind them. [One of the curriculum designers] basically admitted to me that the book was published very quickly. These guys did stuff and the book publishers swept them up, put them in a book and published them. I went in with my fingers crossed, saying, I hope it teaches them something about inquiry. I hope they learn some nature of scientific inquiry. I hope they have a positive experience in the labs. (Post-interview)

For Richard, the adoption of the new laboratory curriculum was an experiment in the sense that he had no reliable reference point from which to judge the efficacy of these labs. The hasty publication of the laboratory curriculum, combined with a palpable sense of desperation to have a laboratory learning environment that students enjoyed, led Richard towards adopting the new, and “unproven,” curriculum.

Richard also believed that the TAs represented the biggest constraint towards successful implementation of the curriculum.

I think the biggest constraint [to successful implementation] is the TAs. I think the implementation of the labs depends strongly on the TA. I think there is a decent amount of raw material in these labs and I think if you push the students and supervise them well and taught them well that they would have. Well, the only data I have is that the students, from the evaluations, the vast majority of the evaluations didn’t like the labs and a lot of the evaluations complained about the quality of the TA. Even some of the English speaking TAs. (Post-interview)

According to Richard, the biggest constraint to the successful implementation of the laboratory curriculum was the quality of the TAs. Richard, however, did not believe that quality TA training was a realistic opportunity in research universities where TAs competing pressures.

The thing they [the TAs] are being told while they're being told they have to be a TA, is that they have to find a research group, they have to find a Ph.D. project, have to pass your classes, you have your qualifiers [qualifying exams] up at the end of the year. And you won't be supported as a TA during your third year. So if you haven't found a research group by the end of your third year, you're out of grad school. So they're not going to invest time in learning how to be a good TA when they've been told, if you're still a TA at the end of your third year you're in trouble, right? So any training program would be difficult. (Post-interview)

According to Richard, the pressure TAs experience in graduate school is too great to allow for any real, meaningful TA training program to be implemented. He followed up by stating that one potential way to solve that problem was to hire an adjunct faculty member whose sole job was to teach the labs. But this, Richard added, was unlikely to occur because it would take away funding from at least eight TAs which meant eight less graduate physics students.

Finally, Richard described the student population as an additional barrier to the success of novel courses such as this.

The students are in the class to get a grade. The vast majority of the students are there to get a grade. Learning some astronomy and enjoying it is a bonus for them. But they are in class to get their scientific requirement at a grade that they feel comfortable with. (Post-interview)

Richard described his students' motivation as originating externally through university requirements rather than internally through personal desire. Richard continued, describing that students did not view the labs as helpful towards achieving a high grade in introductory astronomy.

They see the labs as not helpful towards getting them a good grade. So anything that they perceive as time spent on this class that does not help them improve their grade at the end of the semester, they see as busy work. And they don't see and I don't think it was adequately communicated either by me or by the TAs, what the purpose of those labs were. (Post-interview)

For Richard, students were in his class to fulfill the science requirement of the university. Further, students did not view each introductory astronomy experience as relevant to achieving the highest grade in the course. Hence, Richard believed, students labeled those experiences as busy work and irrelevant. Richard continued, stating that his students likely did not care about learning about the nature of scientific inquiry.

They don't care, they don't want to learn about the nature of scientific inquiry. They want to get an A in astronomy 101 and I'm doing something in the labs that is not helping me do well on the exams. And the exams make up 75% of their grade. The labs make up 25% and so they perceive the exams to be the major component of their grade. (Post-interview)

Richard contrasted students' views of the laboratory experience as irrelevant with their views of the online Mastering Astronomy homework which they perceived as relevant.

They like the Mastering Astronomy because they see that as connected to the material that they are learning in class and beneficial to them in the exam. There's a direct connection between doing Mastering Astronomy and my final grade and doing well on the exams. But I

think that anything that you do in the labs with them that's not connected to them doing well on the final, they see as busy work. (Post-interview)

For Richard, any tasks not explicitly viewed as useful towards achieving a high grade, was viewed as irrelevant, busy work. Richard followed by stating that even if a true connection existed between lab and class, that unless that connection was made explicit by the TA, the students would not be able to make the connection on their own. However, Richard maintained that the TAs likely did not make those connections for the students and further that he himself did not do a good job communicating the importance of the labs during lectures.

To summarize, Richard believed that the laboratory learning environment was unsuccessful based on students' negative end-of-semester course evaluations where students overwhelmingly described the labs as tedious, busy work. Richard formulated several explanations for this. He believed the TAs were unable to effectively supervise their labs and effective supervision was necessary for the success of the laboratory learning environment. Richard described why quality TA training in a research university where TAs have numerous other responsibilities may be impractical, if not impossible. Additionally, Richard described the students as not invested in learning about NOSI. Instead, he described students as desiring to achieve the highest grade possible and students likely did not see labs as helpful towards that goal.

### **Answering the two research questions.**

The two research questions which guided this study were:

(1) *How do a professor and graduate teaching assistants adopt and enact an undergraduate inquiry-based astronomy laboratory learning environment?*



(2) *What is the impact of that laboratory learning environment on students' understanding of the nature of scientific inquiry?* With the previous results in mind, I now respond to both of these research questions.

**Answer to the first research question.**

The first research question asked how Richard and the TAs designed and enacted the new laboratory learning environment. During the early stages of this research, it became apparent that Richard had the sole responsibility for designing the new astronomy laboratory learning environment. Most of the design phase took place before TAs were officially assigned to supervise the labs. Richard designed the laboratory learning environment by adopting existing laboratory materials created by the CAPER team. Their materials consisted of a series of workbook-style problems which students completed during laboratory sessions. Richard designed the laboratory learning environment to consist of students working in groups to complete a particular laboratory activity from this workbook during each lab session. Particular activities from the laboratory materials were selected on a similarity-of-content basis between the lab and lecture. The TAs were to give introductions to each laboratory by explicitly linking the lab material to the lecture content. TAs were also to respond to student questions during laboratory sessions. Limited guidance was offered to TAs to guide them in their roles. During weekly TA meetings, Richard modeled introductions he expected his TAs to give to their students. Very little time was spent guiding TAs' behaviors while interacting with students, however. TAs were told only not to explicitly give answers but to instead ask probing questions.

With this design in place, TAs were in charge of the enactment of the laboratory learning environment. Richard, through the weekly TA meetings, exerted continual influence on this enactment. TAs generally gave similar introductions to Richard's modeled introductions. However, TAs also used introductions as an opportunity to address areas where they believed students would

experience challenges. Addressing potential student problems was not addressed in any formal sense during Richard's introductions. After introductions, students worked in groups and completed the assigned laboratory activity. Most student groups throughout the semester were able to complete the laboratory activity without the assistance of their TA. However, during most labs, at least one or two groups asked questions. TAs interactions with students occurred only when (a) groups were unable to generate a response to a given lab questions or (b) when groups wanted confirmation for their written response to a given lab question. TAs responded similarly during interactions, yet noticeable differences were found. Adam was much more likely to simply tell groups that their written response to a given question was correct or incorrect than Peter was. Peter typically asked the group probing questions to elicit information about criteria that could be used by the group to judge the value of their own responses. Sometimes, however, Peter told the group the criteria. Either way, Peter never directly responded with a simple yes or no.

Richard also gave TAs a grading scheme which they were to use to assess their students' labs. The grading scheme was in the form of a point-allocation system, but examples of sample responses that warranted certain points was not explicitly presented to TAs by Richard. Richard also did not have clear guidance from the CAPER team. As a result, there were several instances where students lost points yet were not provided with a rationale or with any indication of how similar questions could be more adequately addressed in future labs. I provide an explanatory framework which encompasses these findings in the first section of the implications chapter.

### **Answer to the second research question.**

The second research question asked about the impact of the laboratory learning environment on students' understanding of NOSI. I examined the impact of students' NOSI understanding because the CAPER team's associated dissertations argued for the effectiveness of their laboratory materials

based solely on students' increased understanding of NOSI. I found the laboratory learning environment was not effective based on students' naïve views of NOSI after the curriculum, as measured by VOSI. I analyzed the VOSI data in a manner consistent with the analysis procedures of Schwartz et al. (2008). Pre-test VOSI responses were judged to be mainly naïve with the exception of one student in each TA's lab. Post-test VOSI responses were judged to also be mainly naïve, again, with the exception of the same student in each TA's lab. From this analysis, I claim that to the extent that this laboratory learning environment was designed to improve students' understandings of NOSI, this laboratory learning environment was not effective, as measured by VOSI. In the implications chapter, I address whether or not VOSI is the appropriate measuring instrument to gauge the effectiveness of CAPER's laboratory materials and will also comment more generally on the purpose of science instruction.

I also argued that the TAs differed from Richard in terms of their perceptions of the success of the laboratory learning environment. I also described the criteria the TAs used to judge their own success as laboratory instructors. Richard believed the laboratory learning environment was unsuccessful based on students' negative end-of-semester course evaluations. Moreover, Richard believed that the TAs were the main barrier to success and further stated that within research universities it would be nearly impossible to implement any quality TA training programs given the current structure and demands of TAs in research universities. Additionally, Richard speculated that his astronomy students "don't care" and "don't want to learn about the nature of scientific inquiry." Rather, he argued, students wanted to earn an A and perceived any work not helping them in this respect as irrelevant, busy-work. In contrast, both TAs believed that they were successful laboratory teachers based on the lack of student questions throughout the semester as well as the high grades given to their students. Further, both TAs stated that they appreciated the structure of the laboratory

activities and believed that it was likely their students learned about scientific inquiry during the semester as a result of the laboratory curriculum.

In the next and final chapter, I discuss these findings in light of my theoretical frameworks and literature review. In particular, I draw together the threads of the entire Findings chapter into a cohesive narrative.

## **Chapter 5- Discussion and Implications**

In this chapter, I discuss why the enacted laboratory learning environment did not significantly change from Richard's description of the laboratory learning environment of previous semesters. I then discuss why students were able to easily complete the laboratory materials and yet did not improve their understandings of NOSI. I then discuss reasons the VOSI instrument may be problematic in its design and use. I then turn toward the implications of this study. I first describe important issues professors should consider before adopting curriculum materials. I then describe how educative curriculum materials could be developed to help Richard and the TAs effectively supervise the implementation of CAPER's laboratory materials. I end with a critique of the idea that students' understanding of NOS or NOSI is an attainable, or even desirable, learning goal in undergraduate science education.

### **Why the laboratory learning environment did not significantly change**

As a participant in the astronomy education community, I can personally attest to the large number of curriculum materials circulating through various astronomy education outlets. Lecture-tutorials, general student-centered teaching strategies, and laboratory activities abound (see Henderson et al., 2012 for a list of 24 such curriculum materials). Curriculum materials are created by their designers in an effort to influence instructional practices. In fact, this is what Richard hoped would occur when he adopted CAPER's laboratory materials. However, adoption of curriculum materials does not guarantee instructional change (Brown, 2009). In fact, this is what I found in my study. Richard adopted CAPER's laboratory materials with the hope, indeed with the "leap of faith" as he described it, that the enacted learning environment would be different from previous semesters. However, as I argued in the previous chapter, the enacted learning environment did not resemble an inquiry-based learning environment as described in the literature review chapter. In fact, although

Richard's hopes were high, adopting these laboratory materials resulted in very little actual instructional change compared to previous semesters as described by Richard. I argue that there are at least four reasons the laboratory learning environment did not change significantly. First, the *change* relied solely on the adoption of curriculum materials, which themselves cannot result in significant instructional change. Second, Richard received limited guidance on how to use and implement CAPER's laboratory materials. Third, the TAs received limited guidance on how to interact with their students as they worked through CAPER's laboratory materials. And fourth, the learning goals of CAPER's laboratory materials did not fit well into the existing structure and learning goals of the course.

Richard described the laboratory learning environment of previous semesters as relying on "cookbook" materials which students found to be tedious and unrelated to lecture material. He described student questions as driven by a desire to obtain the correct answer which the TA would typically provide. In particular, Richard described the previous laboratory materials as "fill-in-the-blank" exercises that he did not care for because, in his opinion, this was not the way science was done. In an attempt to change this situation, Richard adopted CAPER's laboratory materials. He believed students' questions would be very different from past semesters. According to Richard, the new laboratory materials did not ask simple, numerical questions and so TAs would not be able to give simple, numerical answers. However, very little actually changed in the new laboratory learning environment. Students still disliked the labs, found them tedious and unrelated to lectures, and when they asked questions, those questions appeared to be motivated by a desire to obtain the correct answer, not to gain an understanding of astronomy concepts or of the process of scientific inquiry. The TAs typically gave their students the acceptable responses, either through direct responses or questioning strategies. In addition, both TAs described the laboratory materials as "simple" and

“straightforward” and many students easily worked through the laboratory materials, often without any help from their TA. In essence, students still engaged in “fill-in-the-blank” exercises that they easily completed in most cases and TAs frequently supplied answers.

This description stands in direct contrast to the nature of an authentic inquiry-based learning environment as described in the literature review chapter. Inquiry is *not* a simple, straightforward process. It does *not* involve obtaining known answers to predetermined questions from an authority figure. Yet, this type of authentic inquiry-based learning environment was not realized for this study. Rather, old laboratory materials were replaced with a set of different laboratory materials but the overall nature of the enacted laboratory learning environment remained the same. This provides a specific case of the cautionary words of Brown (2009):

There is good reason to be skeptical about the influence curriculum materials can have over teacher practice, particularly as vehicles for instructional change. The use of curriculum materials provides no guarantee of instructional change. (p. 18)

There is, indeed, good reason to be skeptical of the influence curriculum materials can have on instructional change. Adopting curriculum materials entails only that students complete a different set of materials. It does not necessarily lead to instructional change. Richard did not have prior experience leading professional development programs. Richard also received limited guidance from the CAPER team on how he should use their laboratory materials. Nor did he receive guidance on how he should train his TAs. Richard, as I described previously, was unsure of the learning goals of the laboratory learning environment, even after adopting CAPER’s laboratory materials. Therefore, one reason that the laboratory learning environment did not appear to change significantly from past semester’s is because Richard did not receive sufficient guidance on how to use and implement CAPER’s laboratory materials. Instead, the adopted laboratory materials served as a replacement for

the traditional laboratory materials of past semesters. I will draw implications from this in the next chapter. An additional reason that the laboratory learning environment did not change significantly from past semesters is because the TAs received limited guidance or training for their instructional roles.

In research universities, TAs have a large role in the nature and quality of undergraduate science education in research universities (Gardener & Jones, 2011), yet only receive a minimal amount of support for their instructional roles (Nyquist & Wulff, 1996). In order for TAs to become successful and effective instructors of inquiry-based learning environments, they need to come to value and appreciate those learning environments and experience in learning through inquiry-based teaching (Roehrig et al., 2003; Goertzen et al., 2009) or they may not behave in a manner conducive to sustaining such an environment (Volkman et al., 2005). TAs need to acknowledge and understand their personal beliefs about teaching and learning, and how those beliefs influence their teaching practices. Further, TAs require intensive and ongoing training which is directly connected to new, student-centered teaching practices (Seung et al., 2012; Gardner & Jones, 2011). Student-centered teaching practices entail new representations of content and new teaching strategies to support students' development of conceptual knowledge or skills (Schneider & Krajcik, 2002).

The weekly TA meetings represented the only realistic opportunity where TAs pedagogies could have been developed. Yet, during these meetings, the TAs did not have opportunities to appreciate or understand authentic student-centered learning environments or to become reflective in their teaching practices. Instead, TA meetings became the place where TAs became familiar with the upcoming lab and learned of the laboratory introduction they were expected to give to their students. TAs did not have opportunities to understand or experience inquiry-based learning environments. During these meetings, TAs worked through the laboratory materials after Richard presented an



introduction, just as they were expected to do in their own laboratories. As a result, students also did not engage in inquiry-type behaviors and questions were oriented towards obtaining correct answers to predetermined questions.

One possible way to remedy this situation would be through extensive TA training programs. However, as Richard stated, given the external constraints of TAs, combined with the fact that they are a transient population, intensive and ongoing TA training seems unlikely, especially at research universities. However, this need not lead to complete despair. If on-going, intensive training programs do not sound feasible to research universities then perhaps curriculum developers can create supplemental educative curriculum materials for teachers who adopt their materials (Davis & Krajcik, 2005; Schneider & Krajcik, 2002). Educative curriculum materials are intentionally developed materials which are designed to support teacher learning, while teachers use the materials to support student learning (Schneider & Krajcik, 2002). This support is crucial for the success of any student-centered learning environment because these materials often entail new representations of content and require different teaching strategies and instructional approaches that will likely seem unfamiliar to a novice teacher or a lecture-based teacher. I will turn to the potential use of educative curriculum materials in the implications chapter.

An additional reason the laboratory learning environment did not change significantly is because the laboratory materials did not fit well into the existing structure and goals of the course. As Richard described, he did not have a clear vision for the goals of the laboratory learning environment. Previous activities had been selected on the basis of a superficial relationship to lecture material. Richard was able to clearly articulate content learning goals which, as he explained, he addressed during lectures. However, no such clear goals existed for the laboratory component of the course. Because the course goals were content-oriented, the inquiry-based goals of the laboratory materials

did not fit into the existing course structure because the course goals did not entail that students' engage in, or learn about, scientific inquiry.

In summary, I argued that there were at least four reasons why the laboratory learning environment did not change significantly from past semesters. First, the change was dependent only on adoption of the laboratory materials, but adopting laboratory materials, in and of itself, does not guarantee instructional change. Second, Richard received limited guidance on how to use or implement CAPER's laboratory materials. Third, the TAs received limited guidance on how to interact with their students while they completed the laboratory materials. Fourth, the learning goals of the materials did not fit well into the existing structure and learning goals of the course.

### **Why students easily completed the laboratory materials and yet maintained naïve NOSI views.**

In this study, students were able to easily complete the laboratory activities and yet did not show improvements in their understanding of NOSI. As I argued in the literature review chapter, there is no good reason to think that by engaging in scientific inquiry, one will develop an understanding of the seven NOSI tenets (such as the distinctions between data and evidence or the fact that there exists no single, scientific method). This was a general claim. It is especially true when considering these particular laboratory materials. *Engaging in Astronomical Inquiry* does not generally provide students explicit experiences with any of the seven NOSI tenets. For example, close inspection of the Galaxy inquiry activity (Appendix B) reveals that the terms *data* and *evidence* are used almost interchangeably and with little regard for their important distinctions. Additionally, the term *evidence* is used in varying ways in the assessment activities (Appendix C), and in ways that run counter to the accepted view of evidence as data that has been interpreted in light of a question. For instance, in all assessment activities students are asked to redesign one of the previous three research projects. One question asked students to describe the "step-by-step procedure to collect evidence."

This implies that evidence is collected from a research project, not data. This certainly blurs the distinction between data and evidence. Given this, there are no reasons to think that students, after working through CAPER's laboratory materials, would be able to articulate the fundamental distinctions between data and evidence. With this in mind, I think the most plausible explanation for why students were able to easily complete the laboratory activities and yet not improve their understandings of NOSI is because the VOSI instrument measures a type of knowledge that the laboratory materials do not promote an understanding of.

Lyons (2011) claimed that students in his study *did* develop an understanding of the distinction between data and evidence. I am arguing that the laboratory materials themselves appear to run counter to helping students' develop understandings of these distinctions. It is difficult to see how students could develop an understanding of the distinction between data and evidence given the inconsistent ways in which the two terms are used in the laboratory materials. If we accept Lyons' (2011) findings, this suggests that the professors may have had some role in students' understanding of this distinction. Yet, we cannot know the role of the professor because this study does not describe the nature of the enacted learning environment. Regardless, the type of instruction required to achieve such ends entails, at least, drawing students' attention to the distinct roles that data and evidence play both in the inquiry and the assessment labs. The instruction would also involve drawing students' attention to the nature of the data they collect (quantitative versus qualitative) in addition to how data is used to construct evidence-based explanations and conclusions. Given the ambiguity of these terms in the CAPER materials, this instructional support, in my opinion, is the bare minimum that would be required to help develop students' understanding of the distinctions between data and evidence.

In this study, Richard did not receive guidance on how to help the TAs offer this type of instructional support to their students. It is likely that Richard was unaware of the required

instructional support so he could not develop these skills with the TAs. As a result, the TAs did not provide students with opportunities to understand the distinction between data and evidence.

Therefore, the most plausible reason why students were able to easily work through the laboratory materials and yet did not develop informed views of NOSI is because the materials do not support such an understanding and without additional instructional support given by the TAs, no such understanding would develop.

### **A critique of the VOSI instrument.**

Recall that VOSI is an instrument which assesses students' understanding of the nature of scientific inquiry [NOSI]. In a similar way, the VNOS is an instrument which assesses students' understanding of the nature of science [NOS]. Both instruments were constructed by the same group of researchers (Lederman and his former students) and were developed and pilot-tested in the same way. The VNOS questionnaire has been the subject of recent criticism (Rudge & Howe, 2012; Clough, 2007; Ford, 2008; Allchin, 2011, 2012; Duschl & Grandy, 2012). Therefore, these critiques may also be viewed as appropriate critiques of the VOSI instrument. These critiques generally focus on one of three issues. First, VNOS probes declarative knowledge only. Second, VNOS does not address the challenges of authentic assessment. Third, VNOS may have validity issues.

Many of these critiques argue that the VNOS probes only students' declarative knowledge (Matthew, 2012; Allchin, 2011, 2012). For example, VNOS probes students' knowledge of the following seven NOS tenets: science is empirically-based, scientific theories are different from scientific laws, science requires creativity and imagination, scientific knowledge is theory-laden, scientific knowledge is culturally and socially embedded, there is no single scientific method, and scientific knowledge is tentative, yet durable. Notice that this list of seven tenets is similar in style

and content to the seven tenets that the VOSI questionnaire probes. While most do not necessarily disagree with these statements (at least with qualifiers), to some (Matthews, 2012) this list functions as a checklist; a student is said to possess an informed view of NOS to the extent that the student can articulate those seven tenets of NOS. In this sense, VNOS serves as a mantra to be learned by students. However, in teaching that science has these seven features, these critics argue that this creates an environment that runs directly counter to the very learning goals of critical thinking that most consider the reason for having NOS discussions in the first place. This is because students can easily memorize (as they surely still do) a tenet “science is tentative, yet reliable” and yet not be able to anchor this into a discussion about *why* this is the case. If the goal of particular learning experiences were to memorize certain tenets, such as science is tentative, or scientists are creative, or that there is a distinction between data and evidence (or that the Andromeda galaxy is 2.5 million light years away, or that the universe is expanding), then instruments like the VNOS or VOSI are appropriate. However, if the goal is for students to be able to engage in socioscientific issues they’ll encounter in their lives, it is hard to see how understanding these tenets, alone, could be sufficient.

Others have critiqued the VNOS on the basis that it fails to address the challenges of authentic assessment (Allchin, 2011, 2012, Rudge & Howe, 2012). For example, Allchin (2012) argued that competence, not knowledge, is the target of assessment. Foundational knowledge, of course, is relevant and necessary, but by itself is insufficient. Allchin argues instead that what is important is not *that* students know about the NOS tenets, but *how* they use that knowledge in the form of a *well-reasoned analysis*. For example, he argued, it is not as important to know that science is influenced by cultural and societal factors, but that one can discern how those factors are

expressed in particular socioscientific cases. Allchin (2012) criticized the VNOS for ignoring this crucial dimension when he wrote the following:

In their spirited defense of VNOS and VOSI, Schwartz et al. (2012) fail to address the challenges of authentic assessment or of contextual performance-based assessment. It is telling, I think, that they do not cite any educational research documenting a link between results on VNOS (or VOSI) and either the ability to engage in public discussion of socioscientific issues or the ability to exhibit care (or critical NOS acumen) in assessing scientific information related to our everyday lives. (p. 694)

If the goal of science education is to promote informed “public discussion of socioscientific issues” it is hard to see how understanding the NOS tenets would, by itself, achieve this goal. As I will discuss in the final section of the implications chapter, I agree with this statement.

Others have levied criticisms towards VNOS based on the validity of the instrument itself (for a detailed summary of these criticisms, see Rudge & Howe, 2012). Rudge and Howe (2012) stated that their personal experience in using VNOS has “drawn our attention to how unreliable student responses to written questions can be” (p. 5). They described how speaking with students after administering the VNOS questionnaire revealed discrepancies between their written word and their spoken word. This, of course, is problematic. Additionally, the analysis procedures advocated by the Lederman group do not lend themselves well to measuring small changes in NOSI understanding. That is, by constructing profiles, it is difficult to detect small, and subtle, nuances and changes in students’ understanding of NOSI.

In summary, there are at least three recent critiques that have been levied towards the VNOS instrument, and by association, the VOSI instrument. First, the instruments probe only declarative knowledge. Second, the instruments fail to address the issues of authentic assessment.

Third, the instruments may face validity issues. The third limitation was likely not a problem in this study because of the degree to which student's responses were exceedingly naïve.

### **On adopting curriculum materials.**

As I have argued, adopting curriculum materials does not guarantee instructional change. Professors adopt, and then interpret, add to, omit from, or modify existing curriculum materials in ways that can be very different from the intentions of the curriculum developers. For example, the enacted laboratory learning environment in this study did not resemble an authentic inquiry-based learning environment, as the curriculum developers intended. I also argued that one reason for this disparity involved the fact that the adoption of these laboratory materials was done with little regard for how those materials fit into the overall structure and learning goals set for the course. CAPER's laboratory materials and, in particular, their learning goals, did not fit into the existing structure of the course. Hence, it was not surprising that students described the laboratory materials as unrelated to lectures, and as amounting to "tedious, busy-work," as they had in previous semesters. In other words, adoption of these laboratory materials did not result in instructional change.

I first recommend professors should consider how the learning goals of the adopted materials fit within the existing structure and learning goals of the course. If those learning goals do not fit logically and coherently into the overarching learning goals of the course, then the professor should reconsider the purpose of the adoption. Professors should clarify how adopting the curriculum materials will lead to instructional change or to a change in student learning. However, if professors are unable to articulate such goals, they run the risk of enacting a learning environment that is disconnected, as was the case in this study.

My second recommendation is for professors to consider the degree to which significant teacher-intervention may be required to effectively implement the adopted materials. If such

intervention is required, professors should consider the nature of that intervention and should decide the type of preparation time needed. Moreover, if TAs are the primary teachers, professors should engage with these questions with even more rigor; TAs (likely) will have even less teaching experience. If this is the case, professors should seriously decide whether appropriate amounts of time can be dedicated towards TA training. If adopting curriculum materials is judged to entail significant amounts of TA preparation, preparation that TAs may not want or have time for, and if professors find that their own preparation for that training is highly demanding and time-consuming, then it may not be appropriate to adopt these materials.

My third recommendation is for professors to develop professional relationships with members of science education departments. Such relationships can facilitate mutual benefits: science professors can aid science educators in content knowledge while science educators can aid science professors on how to construct effective student-centered learning environments, how to adapt and use curriculum materials, or how to train TAs. In fact, future research in curriculum materials development or adoption in this university would almost certainly benefit from such a collaboration.

In summary, I presented three general recommendations for science professors. These included ensuring that there is coherence between the learning goals of adopted materials and the general learning goals of the course. I recommended science professors should consider a cost-benefit analysis to adopting materials; if there is insufficient time/resources available, it may not be a prudent use of time to adopt those particular materials. My third recommendation was for science professors to establish professional relationships with science educators. Both parties would likely benefit from this partnership; science professors in terms of pedagogy and science educators in terms of content.



### **On educative curriculum materials.**

Educative curriculum materials are materials designed to support teacher learning, while teachers use the materials to support student learning (Schneider & Krajcik, 2002). This support is crucial for the success of any student-centered learning environment because these materials often entail new representations of content and require different teaching strategies and instructional approaches that will likely seem unfamiliar to a lecture-based teacher. In this section, I discuss how educative curriculum materials [hereafter, ECM] could be designed to help Richard and the TAs use CAPER's laboratory material.

As I argued in the previous section, before adopting any curriculum materials, professors should consider why there was a need for materials in the first place and should be able to articulate reasons that those particular curriculum materials fit well into the overarching structure and learning goals of the course. If unable to articulate such an explanation, more effort and thought should go into describing why there was a need for materials and how the materials can work in favor of existing learning goals. Once curriculum materials have been adopted, the adopters would benefit from some form of support to assist them in using the materials to support student learning. For example, Richard and the TAs in this study may have benefited from having a concrete form of support, with which they could use to facilitate effective implementation of CAPER's laboratory materials. In this vein, supplemental educative curriculum materials can be developed to assist the professor and TAs in implementation. In what follows, I offer practical advice to the CAPER team which may benefit future adopters of their materials. As described previously, I use the design heuristics offered by Davis and Krajcik (2005) to generate this advice (see Appendix A).

First and most crucial, educative curriculum materials [ECM] should clearly articulate for adopters the *learning goals* of those materials. For example, in the case of CAPER's laboratory

materials, the learning goals appeared to be to give students experiences engaging in scientific inquiry. That is, the laboratory materials provided students with opportunities to ask researchable questions, to construct research procedures, to collect and analyze data, and to generate conclusions based on evidence. Further, because these goals are distinct from content learning goals, professors should be provided with a rationale for why adopting inquiry as a learning goal can be useful for them and their students, in terms of content knowledge growth.

Second, ECM should provide a rationale for the particular structure of the activities within the materials, as well as, how those activities are theorized to help students achieve the learning goals, again, in this case engaging students in scientific inquiry. For example, Richard and the TAs may have benefitted from having a description of the nature of the scaffolding support. In particular, Richard and the TAs may have benefitted from understanding the distinction between CAPER's original BFS instructional model and the modified BFS model that adapted for the laboratory materials.

Third, ECM should present sample student responses to various questions within the materials, as well as how to confront and address students' common misconceptions. For example, TAs in this study were often confronted with some variant of the question, "Is this correct?" TAs would have benefitted from having some sort of guidance for these types of questions, which may be common. In particular, materials should provide TAs with a rationale for why short and simple "yes" or "no" responses may not be in the best interest of the student.

Fourth, ECM should give advice to adopters on effective and *specific* questioning strategies to use during instruction. TAs in this study may have benefitted from having guidance on the use of effective questioning strategies. For example, while Peter was able to engage his students in Socratic dialogue, Adam was not. In contrast, Adam typically offered yes/no responses with little or no

follow-up. Again, guidance on how to effectively question students in a way that promotes active engagement and critical thinking would be a useful skill for TAs to develop.

Finally, ECM should provide various modes of assessing whether the learning goals are being met by students. Moreover, ECM should provide a rationale for why particular assessment protocols are appropriate. This, if you recall, was missing from the enacted laboratory learning environment. For example, Richard had limited guidance from the CAPER team regarding assessment and, in turn, TAs did not have clear guidance on how to discriminate between different type of student responses. Adopters would benefit from having a grading rubric they can use to assess their students' written work.

In summary, I have presented four recommendations for the design of educative curriculum materials which might have helped Richard and the TAs effectively adapt and use CAPER's curriculum materials.

### **What is the goal of science instruction?**

For many, the goal of science education is to promote public understanding of science so that individuals can make knowledgeable and well-informed decisions regarding socioscientific issues. For example, purported disagreements between scientists regarding climate change and/or evolution abound in the public mind (as opposed to the relevant scientific communities). Similarly, Jenny McCarthy gives public talks, alleging a link between MMR vaccinations her son received and his subsequent autism diagnosis. Local newspapers talk of the controversies surrounding hydraulic fracturing of rock layers (hydrofracking). These are but a few of the myriad ways in which possessing an understanding of basic science as well as science processes would be helpful. Many science educators have argued that an understanding of the nature of science [NOS] is a requirement for

achieving scientific literacy. The work of the Lederman research group has been highly influential in this respect.

For others, however, this is a misguided approach (Allchin, 2011, 2012; Matthews, 2011). These researchers argue that Lederman's program offers only additional, declarative statements that students are to memorize in addition to their science content (e.g. knowledge is tentative, yet reliable, is culturally and socially embedded, etc.). These researchers argue, convincingly, that there is *no evidence* which documents a link between students' understanding of NOS and their subsequent ability to rationally engage with socioscientific issues in their everyday lives (see, in particular, Allchin, 2011, 2012). Moreover, one of the only published studies which investigated a link between participants understanding of the nature of science and decision-making related to socioscientific issues found no link at all (Bell & Lederman, 2003). They argued that rather than reflecting on the science content, or on a logical analysis of data, participants based their decisions primarily on personal values, morals/ethics, and social concerns.

Some scholars argue for science literacy not in terms of students' understanding of declarative facts about science (regardless of accuracy) but in terms of students' ability to make a *well-informed analysis* of socioscientific issues. The goal here is *not* for students to make an assessment of scientists' knowledge claims, per se. To do that would require one to be an expert in that particular field, a job appropriate for those with a Ph.D. Rather, the goal is to be able to articulate answers to several questions. Rather, the goal is for students to understand things like the nature of evidence, the nature of expertise, the role of the public communication of science, etc. Allchin (2011) describes the kinds of *relevant* questions students would need to be able to address if they are to engage in socioscientific issues.

Whose expertise can be trusted, especially when experts seem to disagree? What forms of

communicating scientific findings to the public are credible? How do scientists manage data? How do they communicate with each other? What kinds of conditions warrant change in scientific consensus? Where does verifiable information end and value judgment begin? (p. 519)

These types of questions, according to Allchin, are fundamentally important. What is *not* important, according to him, is whether students can articulate an understanding in the declarative NOS tenets that the Lederman program advocates for. To bring this into focus, I will use discuss feasible goals of science instruction.

First, the goal of science instruction *should not* only be to produce future scientists and engineers. To be sure, there will be instances where a science professor may inspire a particular student to turn towards the sciences as a professional career. However, the vast majority of students enrolled in science classes, particularly those who are nonscience majors, will not go on to become the next generation' scientists. Rather than science professors attempting to develop future scientists, I believe they should be developing future citizens who are fans of science. For example, I am not particularly skilled at basketball. I can dribble and shoot a foul shot, but that's about it. However, I support basketball teams and cheer for them. In short, I'm a basketball fan. In the same way, I think, we should be developing students to become fans of science; not scientists themselves, but ones who support the basic endeavor of science and have a working understanding of how science and technology impact their lives. The alleged controversies described at the beginning of this section (evolution, climate change, hydrofracking, and the MMR link to autism) provide a context for this idea.

If we, as science educators, follow the learning goals of the Lederman research program, we might develop students' ability to engage in scientific inquiry. If students' can engage in

scientific inquiry then, presumably, they could just “look at the data” themselves can form rational conclusions based on evidence. After all, engaging in scientific inquiry entails collecting data, and constructing evidence-based conclusions. However, I believe this is not the quite the right approach. To be sure, engaging in scientific inquiry can be a useful skill for all students to develop. It can help students understand the connections between data and evidence-based conclusions or the role that research methods play. Yet, no one would seriously consider asking students (or the general population of citizens) to *engage in scientific inquiry* and construct answers to the aforementioned controversies. Indeed, no one would reasonably expect the average citizen to be able to evaluate complex scientific research. Rather, we want citizens to have trust in science. We should want citizens to be able to know who the relevant experts are in a particular field.

In summary, perhaps science educators should focus less on developing students declarative knowledge and more time developing students’ *trust in science*. It is unwise to think students who pursue careers outside of science will be able to evaluate the merit of scientific arguments on their own. This is why we have scientific experts. Instead, science educators should develop students’ trust in science, through various means, so that when faced with socioscientific issues in their *actual, everyday life*, they will better equipped to make decisions which oftentimes appear complex. Being able to respond to questions such as *who’s science claims can I trust?* or *what can I believe about science written by journalists?* or *under what conditions can science consensus change?* will better serve students in their futures than being able to respond to questions such as *what is a scientific experiment?* or *what is the distinction between data and evidence?* or *what is the age of the universe?* As science educators we should focus our energy on developing students’ reasoning ability around the former questions and not the latter.

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## Appendix A

### Design Heuristics from Davis and Krajcik (2005)

(1) Supporting teachers in engaging students with topic-specific scientific phenomena.

Curriculum materials should provide teachers with productive physical experiences that make phenomena accessible to students, as well as, rationales for why these experiences are scientifically and pedagogically appropriate.

(2) Supporting teaching in using scientific instructional representations.

Curriculum materials should provide appropriate instructional representations of scientific phenomena (e.g., analogies, diagrams, models) and support teachers in adapting using those representations and should be explicit about why a particular instructional representation is scientifically and pedagogically appropriate.

(3) Supporting teachers in anticipating, understanding, and dealing with students' ideas about science.

Curriculum materials should help teachers recognize the importance of students' ideas and help teachers identify student ideas within a topic. Curriculum materials should also help teachers gain insight into how they might be able to deal with the ideas in their teaching.

(4) Supporting teaching in engaging students with questions.

Curriculum materials should provide driving questions for teachers to use to frame a unit and should help teachers identify questions that they can use with their students, including focus questions for guiding a class discussion.

(5) Supporting teachers in engaging student with collecting and analyzing data.

Curriculum materials should provide teachers with approaches to help students collect, compile, and understand data and observations; help teachers understand why the use of evidence is so important to scientific inquiry; and help them adapt and use these approaches across multiple topic areas even when the data being collected seem fairly different.

(6) Supporting teachers in engaging students in designing investigations.

Curriculum materials should help teachers recognize the importance of sometimes having students design their own investigations. Curriculum materials should provide guidance for how teachers can support students in doing so, by providing ideas for appropriate designs and suggestions for improving students' inappropriate designs.

(7) Supporting teachers in engaging students in making explanations based on evidence.

Curriculum materials should provide clear recommendations for how teachers can support students in making sense of data and generating explanations based on evidence that the students have collected and justified by scientific principles that they have learned. The supports should include rationales for why engaging students in explanation is important in scientific inquiry and why these particular approaches for doing so are scientifically and pedagogically appropriate.

(8) Supporting teachers in promoting scientific discussion.

Curriculum materials should provide suggestions for how teachers can promote productive communication among students and teachers in conversation and student artifacts. The curriculum materials should provide rationales for why particular approaches for promoting communication are scientifically and pedagogically appropriate.

(9) Supporting teachers in the development of subject matter knowledge.

Curriculum materials should support teachers in developing factual and conceptual knowledge of science content, including concepts likely to be misunderstood by students. Support should be presented at a level beyond the level of understanding required by the students, to better prepare teachers to explain science concepts and understand their students' ways of understanding the material.

## Appendix B

### Galaxies Lab

# 1. What's Way Out There? The Hubble Ultra Deep Field

**Big Idea:** The Hubble Space Telescope image -Hubble Ultra Deep Field<sup>1</sup> reveals a variety of previously unknown objects in the very distant Universe that can be systematically and scientifically counted, organized, and classified.

### Computer Setup and/or Materials Needed:

- a) Access to the image at: <http://www.spacetelescope.org/images/screen/heic0406a.jpg> b) Access to the *SkyWalker* website at:  
<http://www.aip.de/groups/galaxies/sw/udf/swudfV1.0.html>
- c) Note: *There is no expectation that students have studied galaxies prior to completing this research project.*

### Phase I: Exploration

- 1) Access the online Hubble Space Telescope Image at <http://www.spacetelescope.org/images/screen/heic0406a.jpg> You might be able to make it larger and smaller by “left clicking” on the image with your mouse. Most of these objects are galaxies far, far from Earth. However, a few objects are nearby stars, as indicated by -four points<sup>2</sup> on the image, like shown at left.

How many stars can you find? \_\_\_\_\_

- 2) 2. Again, most of these objects are not individual stars, but actually distant **galaxies**—*isolated collections of millions or billions of stars that look like a tiny dot or cloud*. Determine how many galaxies are found in the image. *One strategy to count the number of galaxies in the image is to just count the number of objects in ¼ of the image (the bottom left corner for example) and then multiply the number of galaxies times four to get the total number.*

Total number of galaxies in this image? \_\_\_\_\_

3) Some of the galaxies are orange-red in color, while others are white, and others are blue. What is the most common color of galaxy in the image? *Precisely explain how you determined this.*

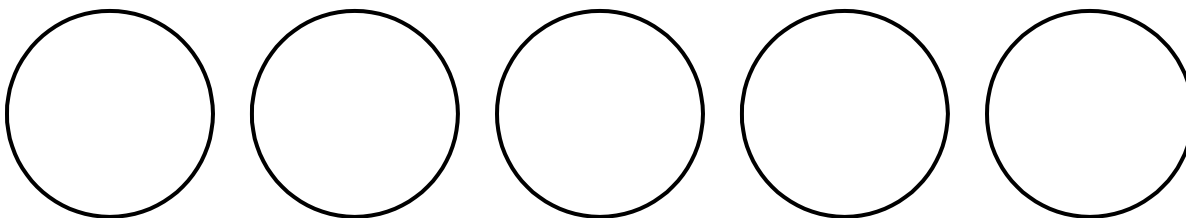
4) If we assume that all of the galaxies in this image have the same diameter, the ones that are close appear larger and the ones that are more distant appear smaller. Are most of the galaxies in this image relatively near or relatively far? What is your evidence?

### **Phase II – Does the Evidence Match a Given Conclusion?**

5) Access the interactive Ultra Hubble Deep Field site through the *SkyWalker* website at:  
<http://www.aip.de/groups/galaxies/sw/udf/swudfV1.0.html>

The green circle in the top left hand corner is a sort of -magnifying glass that you can drag around that will let you look at close up portions of the Hubble Ultra Deep Field. *Note that the picture is about 8 green circles wide and 10 green circles tall, for a total of about 80 green circles over the whole image.*

Make rough sketches of the five closest galaxies you can find in the image.



Consider the research question, -What is the most common type of nearby galaxy? If a fellow student proposed a generalization that **-nearby galaxies are equally split between circular-round and elongated spiral shapes,** would you agree, disagree with the generalization based on the evidence you collected by counting how many of each shape you found? *Explain your reasoning and provide specific evidence either from the above tasks or from new evidence you yourself generate using the SkyWalker Web Site.*

### **Phase III – What Conclusions Can You Draw From This Evidence?**

The Hubble Ultra Deep Field is one of most important images in astronomy because it shows some of the most distant galaxies in the Universe. What conclusions and generalizations can you make from the following data collected by a student by randomly positioning the green circle in an effort to determine WHAT IS THE GENERAL DISTRIBUTION OF GALAXY COLORS? *Explain your reasoning and provide the specific evidence you are using, with sketches or pie charts or graphs if necessary, to support your reasoning.*

GREEN CIRCLE SAMPLE NUMBER	NUMBER OF RED- ORANGE GALAXIES	NUMBER OF BLUE-WHITE GALAXIES
1	7	27
2	10	16
3	15	19
4	10	29
5	12	27

Data collected at <http://www.aip.de/groups/galaxies/sw/udf/swudfV1.0.html>

6) Evidence-based Conclusion:

#### **Phase IV – What Evidence Do You Need To Pursue?**

Imagine your team has been assigned the task of writing a news brief for your favorite news blog about the differences between the numbers of nearby and extremely distant galaxies in the Universe. Describe precisely what evidence you would need to collect, and how you would do it, in order to answer the research question of, **–Are there more nearby galaxies or more extremely distant galaxies?**” You do not need to actually complete the steps in the procedure you are writing.

*7) Create a detailed, step-by-step description of evidence that needs to be collected and a complete explanation of how this could be done—not just “move the green circle around and look at how many big and how many small,” but exactly what would someone need to do, step-by-step, to accomplish this. You might include a table and sketches-the goal is to be precise and detailed enough that someone else could follow your procedure.*

**Phase V – Formulate a Question, Pursue Evidence, and Justify Your Conclusion**

Your task is design an answerable research question, propose a plan to pursue evidence, collect data using the interactive *Ultra Hubble Deep Field* site (or another suitable source pre-approved by your lab instructor), and create an evidence-based conclusion about the characteristics of galaxies in our Universe, which you have not completed before.

**Research Report:**

Specific Research Question:

Step-by-Step Procedure, with Sketches if Needed, to Collect Evidence:

Data Table and/or Results (use additional pages if needed):

Evidence-based Conclusion Statement:



**Phase VI – Summary**      **PRINT YOUR NAME\_\_\_\_\_**

Create a 50-word summary, in your own words, that describes the characteristics and distribution of galaxies in our Universe. You should cite specific evidence you have collected in your description, not describe what you have learned in class or elsewhere. Feel free to create and label sketches to illustrate your response.

## Appendix C

### Assessment Lab

#### Assessment Case Studies #1

#### Assessing & Improving Research

**Big Idea:** Designing a fruitful plan for conducting research has many pitfalls. By assessing the research reports of others, scientists can improve their own ability to design attractive research plans. With better research designs, researchers can improve the support for the claims they make with better and better evidence.

**Goal:** Students will assess a series of research reports and then select one project to redesign and conduct in order to more productively pursue the original research question.

#### **Assess Research Projects & Identify Inconsistencies in their Lines of Inquiry**

Your task is to improve research projects similar to those you have already completed. Work improving only on one research report at a time. Make sure to specify which report you are using by completely writing out the research question. Answer each of the questions by circling *yes*, *no*, or *maybe*, and then provide a short, but detailed, explanations of your reasoning citing specific information from the provided research reports.

## **Inquiry Research Report #11**

### **Monitoring the Moving Constellations**

#### **Formulate a Question, Pursue Evidence, and Justify Your Conclusion**

Your task is design an answerable research question, propose a plan to pursue evidence, collect data using heavens-above (or another suitable source pre-approved by your lab instructor), and create an evidence-based conclusion about some motion or position in the sky for the constellations which you have not completed before.

#### **Research Report:**

Specific Research Question:

During which season is the constellation Orion high in the southern sky just after sunset?

Step-By-Step Procedure to Collect Evidence:

Using heavens-above.com to make observations:

1. Chose a day of the month to observe
2. On each observation day, just after the sunset determine if *Orion* is visible and determine in which part of the sky it is located
3. Repeat the observation once a month for a year

Data Table and/or Results:

Date	Visible	Location		Date	Visible	Location
4/1/09	yes	high SW sky		10/1/09	no	n/a
5/1/09	yes	low W sky		11/1/09	no	n/a
6/1/09	no	n/a		12/1/09	no	n/a
7/1/09	no	n/a		1/1/10	yes	low E sky
8/1/09	no	n/a		2/1/10	yes	high SE sky
9/1/09	no	n/a		3/1/10	yes	high S sky

Evidence-based Conclusion Statement:

From the evidence above, we can see that the constellation Orion appears to move from low in the Eastern sky to low in the Western sky from January to May.

### **CASE STUDY RESEARCH REPORT #11:**

1. Specific Research Question: \_\_\_\_\_

What list of things might you observe to pursue this research question?

2. Step-by-Step Procedure to Collect Evidence:

Is the plan presented going to yield the necessary evidence needed to fully answer the listed research question?

*Detailed Explanation:* (only if you answered No or Maybe) *Circle one:* Yes | Maybe | No

3. Conclusions Drawn from Data Table and/or Results of Evidence

Has enough evidence been collected for this specific research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

Have they claimed more than the evidence supports?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

4. Evidence-based Conclusion Statement:

Have assumptions impacted their results?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

Does the claim directly answer the original research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

5. Precisely, what should the researchers have done or reported differently to improve their inquiry research project?

## **Inquiry Research Report #12**

### **Observing the Sun's Position and Motion**

#### **Formulate a Question, Pursue Evidence, and Justify Your Conclusion**

Your task is design an answerable research question, propose a plan to pursue evidence, collect data using heavens-above (or another suitable source pre-approved by your lab instructor), and create an evidence-based conclusion about some motion or position of the sun in the sky which you have not completed before.

#### **Research Report:**

Specific Research Question:

Over the course of a year, how does the amount of sunlight each day at the equator compare to that of Laramie, WY?

Step-By-Step Procedure to Collect Evidence:

Use heavens-above.com to make observations:

1. Choose a number of days over the course of a year to make observations.
2. Observe and record the sunrise and sunset times on each of the of the observation days in Laramie, WY and at the equator.
3. Use the sunrise and sunset times to calculate the total amount of daylight on each of the observation days and at both locations.

Data Table and/or Results

(All times are Mountain Standard Time)

Date	Laramie Sunrise	Laramie Sunset	Total Daylight	Equator Sunrise	Equator Sunset	Total Daylight
3/8/2009	6:25 am	5:50 pm	11:35	6:10 am	6:08 pm	11:58
3/15/2009	6:15 am	6:00 pm	11:45	6:09 am	6:06 pm	11:57
3/22/2009	6:00 am	6:05 pm	12:05	6:08 am	6:04 pm	11:56
3/29/2009	5:50 am	6:15 pm	12:25	6:05 am	6:02 pm	11:57

Evidence-based Conclusion Statement:

Over the course of a year, the sun rises earlier and sets later in the summer than in winter in Laramie, WY, so there is more daylight in summer and less in winter. The equator does not experience seasons so there is no change in the amount of daylight as the year progresses.

**CASE STUDY RESEARCH REPORT #12:**

6. Specific Research Question: \_\_\_\_\_

What list of things might you observe to pursue this research question?

7. Step-by-Step Procedure to Collect Evidence:

Is the plan presented going to yield the necessary evidence needed to fully answer the listed research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

8. Conclusions Drawn from Data Table and/or Results of Evidence

Has enough evidence been collected for this specific research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

Have they claimed more than the evidence supports?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

9. Evidence-based Conclusion Statement:

Have assumptions impacted their results?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

Does the claim directly answer the original research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

10. Precisely, what should the researchers have done or reported differently to improve their inquiry research project?



## **Inquiry Research Report #13**

### ***Monitoring the Zodiac Constellations***

#### **Formulate a Question, Pursue Evidence, and Justify Your Conclusion**

Your task is design an answerable research question, propose a plan to pursue evidence, collect data using heavens-above (or another suitable source pre-approved by your lab instructor).

#### **Research Report:**

Specific Research Question:

Does the altitude of the line of the Zodiac constellations through the sky change over the course of a year in the same way as the path of the Sun? That is, does it move higher and higher above the southern horizon in spring and move lower and lower toward the southern horizon in fall?

Step-by-Step Procedure to Collect Evidence:

Use heavens-above.com to make observations:

1. Choose a day of the month to observe the Zodiac
2. Each month, right after sunset, record the direction & time the Zodiac is rising
3. For clarity, label directions as; northeast, NE; east-northeast, ENE; east, E; east-southeast, ESE; etc.

Data Table and/or Results:

Date: Day of the year for observation; Time: Time after sunset when Zodiac was observed

Direction: The direction on the horizon where the zodiac was rising

Date	Time	Direction			Date	Time	Direction
1/15/2009	5:00pm	ENE			7/15/2009	8:30pm	ESE
2/15/2009	5:30pm	ENE			8/15/2009	8:00pm	ESE
3/15/2009	7:15pm	E			9/15/2009	7:15pm	E
4/15/2009	7:45pm	E			10/15/2009	6:15pm	E
5/15/2009	8:15pm	ESE			11/15/2009	4:45pm	ENE
6/15/2009	8:45pm	ESE			12/15/2009	4:30pm	ENE

Evidence-based Conclusion Statement:

Every month the path of the Zodiac appears to move lower and lower from summer all the way through fall. After winter starts, the path moves higher and higher above the horizon throughout spring until summer. This is nearly identical to the changes that the path of the Sun takes throughout the year, and also accounts for the changes in the seasons.

**CASE STUDY RESEARCH REPORT #13:**

11. Specific Research Question: \_\_\_\_\_

What list of things might you observe to pursue this research question?

12. Step-by-Step Procedure to Collect Evidence:

Is the plan presented going to yield the necessary evidence needed to fully answer the listed research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

13. Conclusions Drawn from Data Table and/or Results of Evidence

Has enough evidence been collected for this specific research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

Have they claimed more than the evidence supports?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

14. Evidence-based Conclusion Statement:

Have assumptions impacted their results?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

Does the claim directly answer the original research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

15. Precisely, what should the researchers have done or reported differently to improve their inquiry research project?

**Choose One Research Project to Redesign, Improve, and Conduct**

Your task is to choose one of the research projects (either report 12 or report 13) to redesign and carry out. You should re-use the exact same research question as the previous researchers, but make sure to improve the research design so that you eliminate all the problems you were able to identify. At the end, check over your research by answering the assessment questions about your own inquiry report.

**Your Redesigned Research**

Report: Specific Research

Question:

Step-by-Step Procedure to Collect Evidence:

Data Table and/or Results:

Evidence-based Conclusion Statement:

**REDESIGNED RESEARCH REPORT:**

16. Specific Research Question: \_\_\_\_\_

What list of things might you observe to pursue this research question?

17. Step-by-Step Procedure to Collect Evidence:

Is the plan you used going to yield the necessary evidence needed to fully answer the listed research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

18. Conclusions Drawn from Data Table and/or Results of Evidence

Has enough evidence been collected for this specific research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

Have you claimed more than the evidence supports?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

19. Evidence-based Conclusion Statement:

Have assumptions impacted your results?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered Yes or Maybe)

Does the claim directly answer the original research question?

*Circle one:* Yes | Maybe | No

*Detailed Explanation:* (only if you answered No or Maybe)

20. Precisely, what has been done or reported differently improving the original inquiry research project?

**Phase VI – Summary****PRINT YOUR NAME\_\_\_\_\_**

Write a 50 word summary of what makes a solid inquiry research project. Include reason(s) why you elected to improve the project you did, explain what the biggest problems were, and how you corrected them. Be sure to describe details about how your changes improved the line of inquiry.

In general, what are some common problems you need to avoid in designing a solid research project?

In general, what are some important things to consider about assumptions you make in your research design?



## Appendix D Syllabus

### 1 General Information

#### Lectures and Labs

Lecture section M001: Tuesday, Thursday 12.30pm–1.50pm

Lecture section M002: Tuesday, Thursday 2pm–3.20pm

#### Office Hours

Wednesday 4.30pm–6.30pm, Friday 2pm–4pm, or by appointment. Please feel free to see me during office hours or by appointment to discuss any difficulties or questions you have regarding the course.

#### Textbooks

The following books are required for the course:

- Investigating Astronomy: A Conceptual View of the Universe 1st edition. Slater and Freedman. (W. H. Freeman & Company.) ISBN-13 978-1429210638. This is textbook for the class and the syllabus contains required reading from this text.
- Lecture Tutorials for Introductory Astronomy 2nd edition. Prather, Slater, Adams and Brissenden. (Addison-Wesley/Pearson.) ISBN 0132392267. This book will be used in class.
- Engaging in Astronomical Inquiry. Slater, Slater and Lyons. (W.H. Freeman & Company.) ISBN-13 978-1429258609. This book is the required lab manual.

These books are available in a package from the Bookstore. If you purchase them separately, you must make sure that you purchase all of these items (including Mastering Astronomy) otherwise you will not be able to complete lab and homework assignments.

We will be using the Lecture Tutorials for Introductory Astronomy in class, so it is important that you **bring your Lecture Tutorial book to every lecture**. You must also **bring your copy of Engaging in Astronomical Inquiry to every lab section**.

## 2 Course Description

Astronomy 101, Our Corner of the Universe, is devoted to an understanding of the solar system and our place in it. We will discuss our Earth, the Sun and the Moon, and the planets. We will also deal with simple aspects of the sky, including observations. You will be required to think about how we have gained such a sophisticated understanding of this part of the Universe, not simply to learn the currently accepted facts. In the process, we hope you will better appreciate the nature of scientific inquiry and its human elements.

The overarching goals of this course are for you to understand the nature of science through the eyes of astronomy; to understand the big ideas in astronomy; and to develop a lifelong interest in astronomy and current events surrounding astronomy. To meet these three goals, we have carefully designed a sequence of learning tasks and assessment procedures as outlined on the following pages.

## 3 Lectures

I will give the course lectures. Attendance is required at lectures. Material will be covered in the lecture that is not available elsewhere. 10-40% of each exam will be drawn from such material. Questions during lecture are welcome. You are responsible for all announcements regarding curriculum, schedule, etc. made during lecture.

Carefully studying the textbook is required. The course lectures are designed to focus on the difficult aspects of astronomy, to provide structure for your out-of-class study, and to provide demonstration of concepts we will encounter. You are accountable for all material, concepts, and interrelationships presented in the lectures, the text, and the Lecture Tutorials. Therefore, it is imperative to your success in this course that you complete the assigned readings **prior to coming to class**. Reading assignments should be completed before the class they are listed with. Otherwise, the lectures and labs will be less useful in helping you develop a deep understanding of the course topics. It may be useful to bring your text with you each day to class so that you can make notes in the margins and highlight the relevant passages. It is important to remember that the exams will cover material from the text readings that may or may not be discussed in class.

It is our belief that you can only learn a limited amount of information from the lectures alone, no matter how clear or entertaining. Therefore, this course is composed of a series of lectures that will be augmented by collaborative classroom activities called Lecture Tutorials (LT). The LT activities target specific ideas presented in lecture and are designed to be completed in small groups (2 to 4 students) by talking through the questions and writing a detailed, consensus response.

**We will use the LTs regularly in lectures.** The LTs completed in class will not be submitted for grading. However the LT questions are quite similar to the questions you will find on the exams. You should consider the LTs to be a critical component of your success in the course. You are strongly encouraged to discuss your solutions with your peers and not work alone on the LTs. Written solutions to the LTs will **not** be provided; this undermines the purpose of the LTs and turns them into just another textbook. However, you are **strongly encouraged** to discuss your solutions with me in office hours if you would like feedback on your work. The LTs are available at the bookstore and they must be brought to every lecture.

Please turn off cell phones before you enter the classroom. Also, please do not leave class early unless you have talked to the college teacher in advance. These requests are both for issues of safety as well as consideration for your fellow students.

Credit will be given for class participation exercises, which will be assigned and collected from time to time in lectures. We will **NOT** be using “clickers” in the Astronomy 101, therefore you do **NOT** need to purchase a clicker for the lectures in this course.

## 4 Homework

During the semester you will be required to complete homework assignments that are designed to assess your understanding of the material covered in the course text and in lectures. **No late homework will be accepted for any reason.** The homework can be found on the Mastering Astronomy web site. To access this site you will need the code in the “Student Access Kit” included with your textbook. If you do not have this, you may purchase an access code from the Mastering Astronomy web page at the address below.

The due dates for the homework are given in the schedule below. You are responsible for making yourself aware of these deadlines and ensuring that you have enough time to complete the assignments.

Homework is automatically posted at 5:01pm on a Tuesday and is due at 5pm the following Tuesday. Homework submitted after the deadline will receive a zero grade. This includes reasons involving technical difficulties in completing the work. Do not wait until the last minute to start the homework in case you have problems with your computer and/or Internet connection. Mastering Astronomy is compatible with most browsers. The computers in the undergraduate ITS labs are known to work. If you have problems with your own computer, make sure you give yourself enough time to

use an ITS computer. See the college teacher **before the homework is due** if you are having problems.

To complete a homework assignment, you need to answer each question and then click submit. Then you need to submit each part of the homework. Once you have submitted all parts, you should see the message "You completed this assignment" when you view the assignment. See the example screen shot in the Homework section on blackboard to familiarize yourself with the completed message.

## 5 Astronomy Laboratory

AST101 satisfies the "laboratory course" requirement of the liberal arts core and so it has a compulsory lab component. Many important course activities take place in the laboratories. The lab exercises are taken from the required textbook *Engaging in Astronomical Inquiry*, so you **must bring your copy to every lab section**. You will hand in the pages from this lab book for the TA to grade, so if you do not have a copy of this book, **you will get a zero score for the lab**.

**Note:** All lab assignments except labs 1, 9 and 12 have a pre-lab exercise, which will familiarize you with the particular activity you will be doing in lab. You should complete the section labeled "Phase 1: Exploration" for that week's lab exercise before you attend the lab. If Phase 1 has multiple parts (e.g. A, B, C, etc.) you should complete all of these before the lab.

**Anyone missing more four or more labs will receive a grade of zero for the lab portion of the course! There are NO make-up labs, so if you do not attend a lab or you fail to return your work for grading, you will receive a zero for that lab and it will count as a missed lab.**

A small course fee is charged which helps pay for (i) handouts which are distributed to you; (ii) computers, supplies, small pieces of apparatus, and maintenance for the laboratory and observatory; (iii) supplies and apparatus for lecture exercises and demonstrations; and (iv) maintenance of the telescopes used for observing sessions.

Many of the laboratory exercises require a laptop computer to complete. We will provide a loan laptop to each group in the laboratory, but you are also encouraged to bring your own laptop, if you wish.

It is imperative that you attend your weekly laboratory meeting. You will work on the assignments in small groups (2 or 3 students) in the lab and turn in the completed

assignments from your workbook at the end of lab. Each student must turn in a completed assignment to obtain a grade.

If you are unable to attend your assigned lab, you may contact your TA in advance and ask if you can attend a different lab session that week. Management of temporary switches is at the discretion of the TAs. If your lab conflicts with a regular class or other appointment, see the physics secretary to enquire about switching lab sections.

There are 12 lab exercises and each is graded out of 30 points. To compute your total score for the lab portion of the class, I will drop the lowest lab score and add together the scores from the remaining eleven labs for a maximum score of 330. This score will be divided by 6.6 to give a final grade out of 50 for the lab portion of the class. Remember: anyone missing more than four or more labs will receive a grade of zero for the lab portion of the course. This includes the lab dropped from your final score.

## **Exams**

### **Mid-term exams**

There are three mid-term exams and one final in this class. Mid-term exams will be given in class on the following dates:

- Mid-term exam 1: Tuesday September 27, 2009.
- Mid-term exam 2: Thursday October 20, 2009.
- Mid-term exam 3: Thursday November 17, 2009.

Mid-term exams will consist of 30 multiple choice questions. Mid-term exams cover all material since the previous exam.

**Please do not make any plans that interfere with scheduled exams as there are NO late or make-up exams given.**

### **Final Exam**

The final examination date is set by the University Registrar and will be announced in class. Designated final examination dates and times are not subject to change either by student or faculty request. Students are responsible for scheduling their courses, and thus their final examinations. The university does not limit the number of final examinations for which a student may be scheduled on any given examination day.

The final exam is a 50 question comprehensive exam that will cover **all** the material discussed in the course.

**The final is compulsory and there is no make-up final exam. If you miss the final, you will get zero points for the final exam.**

### **Exam Conduct**

Exam questions will come from lectures, texts, recitations, and homework. Bring several #2 pencils. Seats will be assigned and posted in the lobby of the auditorium before each exam. IDs may be checked, so bring your ID card. Exams will not be returned, but may be examined with me in office hours. All questions concerning the grading of exams should be submitted on the re-grade request form, available. Regrade request forms must be submitted within seven days of the date of the exam. After this time, grades are final and cannot be changed.

During the closed-book, closed-note exams, you are not allowed to wear headphones, or allowed to communicate with anyone in the classroom except for the course instructors and exam proctors. Cell phones must remain off at all times during exams. If you have been certified as needing to take an exam under special circumstances, please see me privately, according to the ODS policies.

Student athletes who have university-sanctioned travel that conflicts with a mid-term exam must inform me before the date of the exam. Students must have written permission from the athletics department. Student athletes will be given the choice of either dropping the exam as their lowest score or taking an oral examination in lieu of the written exam.

If you miss a mid-term exam for **any reason**, you will **not** be allowed to make up this exam, rather, it will be the exam that you drop as your lowest score. You **cannot** miss the final exam and there are no opportunities to take it at a different time.

## **7 Grading**

All homework except for the first week's assignment (Introduction to Mastering Astronomy) will be graded. The remaining homework assignments will count the equivalent of one mid-term exam. I will drop the lowest score out of the three mid-term exams and the homework (i.e. your score will be based on three mid-term exams, or two mid-term exams and the homework). The maximum score for the mid-term exams and homework is 90 points. The final exam will be worth 50 points and the lab exercises will be worth 50 points.

10 points are available for lecture participation, assigned as follows: if you complete 70% or more of the lecture participation exercises you will receive 10 points, if you complete 50% or more of the lecture participation exercises you will receive 5 points, if you complete less than 50% of the lecture participation exercises then you will not receive any participation points.

The course grade breakdown is as follows:

- Highest scores from the three mid-term exams and all the class homework exercises: 90 points (30 points per exam or for the homework).
- Final exam: 50 points.
- Lab grade: 50 points.
- Participation credit: 10 points.

Thus your maximum score will be 200 points. To pass, you need 112 points (56%). To be guaranteed an A-, you will need 180 points. (90%). Grading will not be curved.

## 11 Class Schedule

The reading assignments, homework and lab schedule are given on the following pages. Make sure you complete the reading **before** coming to class. You should also make sure you complete the pre-lab exercise. Note that there are no exemptions given for missing deadlines.

# Astronomy 101: Our Corner of the Universe

The course is divided into four parts: “Patterns in the Sky,” “From Ancient Greek to Modern Astronomy,” “Understanding Our Star: The Sun,” and “Understanding Our Planet: The Formation of the Solar System and the Earth.” Each of these parts builds on the previous to give you an understanding of both our place in the universe and how humans came to acquire our current knowledge of astronomy.

Reading assignments are from the required textbook “Investigating Astronomy” by Slater

and Freedman. Lab assignments can be found in the book “Engaging in Astronomical

Enquiry” by Slater, Slater and Lyons.

**Note:** Lab assignments except lab 1, 9 and 12 have a pre-lab exercise, which will familiarize you with the particular activity you will be doing in lab. You should complete the section labeled *Phase 1: Exploration* for that week’s lab exercise **before** you attend the lab. If Phase 1 has multiple parts (e.g. A, B, C, etc.) you should complete all of these before the lab.

Make sure you bring your copy of “Lecture Tutorials For Introductory Astronomy” to **all** lectures.

## Part One. Patterns in the Sky

Learning Goals: To understand the motion of the Sun, the Moon and the Stars.

Date	Lecture	Homework	Lab
Tuesday August 30	1. Introduction to Astronomy <i>Reading: Section 1-1</i>	Introduction to Mastering Astronomy  Due 8pm, September 6	Lab 1: Diagnostic Quiz  Monday 8/29 - Friday 9/2
Thursday September 1	2. The Celestial Sphere <i>Reading: Section 1-2</i>		
Tuesday September 6	3. Daily Motion of the Sky <i>Reading: Section 1-3</i>	The Scale of the Universe and the Celestial Sphere  Due 8pm September 13	No Lab 9/5 - 9/6
Thursday September 8	4. Annual Motions of the Sky <i>Reading: Section 1-4</i>		Lab 2. Observing the Sun’s Position
Tuesday September 13	5. Seasons, Equinoxes and Solstices <i>Reading: Section 1-4</i>	Motions in the Sky and Seasons  Due 8pm September 20	Wednesday 9/7 - Tuesday 9/13
Thursday September 15	6. Phases of the Moon <i>Reading: Section 1-5</i>		Lab 3. Constellations



Tuesday September 20	7. Predicting Phases and Eclipses <i>Reading: Section 1-6</i>	Phases of the Moon  Due 8pm September 27	Wednesday 9/14 - Tuesday 9/20
Thursday September 22	8. Precession of the Equinoxes		Lab 4. Assessment Case Studies #1
Tuesday September 27	Mid-term Exam 1 Covers all material in part 1 of the class		Wednesday 9/21 - Tuesday 9/27

## Part Two. From Ancient Greek to Modern Astronomy

Learning Goals: To understand humans moved from the Earth-centered universe to our modern understanding of astronomy and our place in the universe.

Date	Lecture	Homework	Lab
Thursday September 29	9. Greek Astronomy <i>Reading: Section 3-1</i>	Greek Astronomy Due 8pm, October 4	Lab 5: What's Way Out there?
Tuesday October 4	10. Parallax and Distance <i>Reading: Section 10-1</i>	Parallax and Modern Astronomy  Due 8pm October 11	Wednesday 9/28 - Tuesday 10/4
Thursday October 6	11. The Copernican Revolution <i>Reading: Section 3-2, 3-3</i>		Lab 6: Observing Jupiter's Moons
Tuesday October 11	12. Kepler's Laws of Planetary Motion <i>Reading: Section 3-4</i>	Kepler's and Newton's Laws  Due 8pm October 18	Wednesday 10/5 - Tuesday 10/11
Thursday October 13	13. Newton's Laws of Motion <i>Reading: Section 3-5</i>		Lab 7: Extra Solar Planets
Tuesday October 18	14. Newton's Theory of Gravity <i>Reading: Section 3-6</i>		Wednesday 10/12 - Tuesday
Thursday October 20	Mid-term Exam 2 Covers all material in part 2 of the class		No lab 10/19 - 10/21

## Part Three. Understanding Our Star: The Sun.

Learning Goals: To use the information encoded in light to understand where the Sun's light and energy comes from.

Date	Lecture	Homework	Lab
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Tuesday October 25	15. The Nature of Light <i>Reading: Sections 2-1 and 2-2</i>	Light and Black Body Spectra	No lab 10/24 - 10/25
Thursday October 27	16. Blackbody Radiation and Spectra <i>Reading: Sections 2-3 and 2-4</i>	Due 8pm, November 1	Lab 8: Assessment Case Studies #2
Tuesday November 1	17. Absorption and Emission Spectra <i>Reading: Section 2-3 and 2-4</i>	Spectra and Telescopes  Due 8pm November 8	Wednesday 10/26 - Tuesday
Thursday November 3	18. Telescopes <i>Reading: Section 2-6</i>		Lab 9: Spectra Lab
Tuesday November 8	19. The Sun: Nuclear Fusion and Energy <i>Reading: Sections 9-1 and 9-2</i>	The Sun  Due 8pm November 15	Wednesday 11/2 - Tuesday
Thursday November 10	20. The Sun: The Structure of the Sun <i>Reading: Sections 9-3, 9-4, 9-5</i>		Lab 10. Features of the Sun
Tuesday November 15	21: The Gravitational-Wave Spectrum <i>Reading will be posted on blackboard</i>		Wednesday 11/9 - Tuesday 11/15
Thursday November 17	Mid-term Exam 3 Covers all material in part 3 of the class		No Lab 11/16 - 11/18

### Part Four. Understanding Our Planet: The Formation of the Solar System and the Earth

Learning Goals: To understand how the Sun and the planets of our solar system formed. By comparing our planet with Venus, understand the conditions necessary for life on Earth and how human activity affects the Earth's atmosphere.

Date	Lecture	Homework	Lab
Tuesday November 22	Thanksgiving Break: No Class.	No homework due on November 29	No lab 11/21 - 11-25
Thursday November 24	Thanksgiving Break: No Class.		
Tuesday November 29	21. Formation of the Solar System <i>Reading: Sections 4-1, 4-3, 4-4, and 4-5</i>	The Solar System  Due 8pm December 6	Lab 11: Poster Conference
Thursday December 1	22. Uncovering Earth's Systems <i>Reading: Sections 5-1, 5-2, 5-3</i>		Monday 11/28 - Friday 12/2
Tuesday December 6	23. Terrestrial Planets <i>Reading: Sections: 6-1, 6-2, and 6-3</i>	The Greenhouse Effect	Lab 12: Post-tests

	Thursday December 8	24. Planetary Atmospheres <i>Reading: Sections 5-4, 5-5, 6-4</i>	Due 8pm December 13	Monday 12/5 - Friday 12/9

## **Appendix E**

### **Professor Pre-interview**

- (1) Could you please describe your previous education? Why astronomy?
- (2) Could you please describe your teaching experiences? Which courses? How did you teach them?
- (3) Can you please describe any professional development programs that you have participated in? What kinds of things did you learn? Have you adapted any techniques from this program into your own teaching?
- (4) What are the learning goals for this course? How did you choose these goals?
- (5) Can you describe what a typical lecture might look like? How about the accompanying labs?
- (6) What are the goals for the laboratory component of this course?
- (7) Could you tell me about the nature of these new labs? How are these labs different than other science labs they may have done? Why did you decide to adopt these particular laboratory activities?
- (8) Can you please describe the nature of the weekly TA meetings you'll hold?
- (9) Do you anticipate any problems or constraints with these new labs and learning environment?
- (10) Do think that the TAs can effectively teach these labs? Do you think the students can successfully complete these inquiry labs?
- (11) How confident do you feel that you can successfully enact this inquiry-based laboratory curriculum taught by TAs? Does anything concern you?

## **Appendix F**

### **Professor Post-interview**

- (1) What were the biggest challenges and constraints that you've discovered with implementing these inquiry labs?
- (2) Overall, how well do you think the TAs responded to having to teach these labs? How well did the students respond? Have you received any feedback?
- (3) How confident are you that you've achieved the laboratory goals you set at the beginning of the semester [draw from previous interviews]? How confident are you that you can successfully implement this curriculum with the TAs in the future?
- (4) Will you continue to use these inquiry labs in the future? Why?

## **Appendix G**

### **TA Interview #1**

- (1) Could you please describe your previous education? Any astronomy?
- (2) Could you please describe your teaching experiences? Which courses? What were your responsibilities?
- (3) Can you please describe any TA-training that you have participated in? What did you do in the training? How long was the training? What kinds of things did you learn?
- (4) Could you tell me a little bit about this lab-portion of the course? What are the goals?
- (5) You will be in charge of teaching several sections of astronomy labs. What are the nature of those labs?
- (6) What do you hope to gain from this teaching experience? Do you consider yourself passionate towards teaching? When you're done here will you be teaching, doing research, both?
- (7) What kinds of experiences have you had with TA meetings in the past? What did you typically do during a meeting? Do you think this experience will be similar?
- (8) Do you anticipate any problems with teaching these labs?
- (9) How confident do you feel about teaching these inquiry labs? Does anything concern you?

## **Appendix H**

### **TA interview #2**

- (1) You said before that you were worried about [draw from previous interview]. Have your views changed at all? Why?
- (2) How have the student responded to these inquiry labs? Why do you think they've responded that way?
- (3) How useful have you found the weekly TA meetings?
- (4) You said before [draw from responses from first interview]...have your thoughts changed at all? More confident? Less? Why? Why not?
- (5) How motivated you are to continue using these labs? Would you prefer another format?

## **Appendix I**

### **TA interview #3**

- (1) Overall, what were the biggest challenges and constraints you faced this semester teaching these labs?
- (2) Overall, how well do you think the students responded to having to teach these inquiry labs? Have you received any feedback?
- (3) Overall, how well do you think the TA meetings were at preparing you to teach these labs?
- (4) How confident are you that you were successful as a TA this semester?
- (5) Would you ever want to teach these kinds of labs again?



## Appendix J

### VOSI Questionnaire

Name: \_\_\_\_\_

Date: \_\_\_\_\_

**Directions:** This survey asks you to think about your views of science. There are no right or wrong answers and this assignment will *not* be graded. I would like to understand your ideas about science and how science is done. Please answer all of the following questions. You may use all the space provided to answer a question.

1. A lot of science relies on terminology.

(a) What do you think a scientific experiment is? Give an example to support your answer.

(b) What does the word *data* mean in science?

(c) Is *data* the same or different than *evidence*? Please explain.

2. A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that animals who ate similar types of food tended to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tended to have teeth that were sharp and jagged. They had large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, had smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.

(a) Do you consider this person's investigation to be an **experiment**? Please explain why or why not.

(b) Do you consider this person's investigation to be **scientific**? Please explain why or why not by describing what it means to do something "scientifically."

This investigation is / is not (circle one) scientific because:

3. The “scientific method” is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?

\_\_\_\_\_ **YES, scientists must follow the scientific method**

\_\_\_\_\_ **NO, there are many scientific methods**

-Please answer **only** (a) OR (b) below depending on your response above-

(a) If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.

(b) If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.

**4.** Models are widely used in science. What is a scientific model? Describe and give an example in the appropriate spaces below.

(a) A scientific model is:

(b) An example of a scientific model is:

**5.** Scientists do lots of investigations and then share their findings with other people. They publish their work in scientific journals. They speak about their work at meetings and even on TV. How do scientists know when they are ready to make their research results public? What kind of information do they need in order to convince others that their findings are valid (believable)?

END  
SURVEY

### **Vita**

Steve Stewart has a background in physics and astronomy and has become increasingly interested in curriculum development and teacher training. In particular, he is interested in the relationship between curriculum materials, the teachers who adopt them, and the resulting learning environment. His future projects involve the development and impact of TA training programs, the development of astronomy laboratory curriculum materials, and the development of educative curriculum materials which support teachers in the classroom.